

Vision Sciences Society

11th Annual Meeting, May 6-11, 2011
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Abstracts

Contents

Sessions Overview	2	Monday Morning Talks	198
Member-Initiated Symposia	4	Monday Morning Posters	206
Friday Evening Posters	13	Tuesday Morning Talks	226
Saturday Morning Talks	36	Tuesday Morning Posters	234
Saturday Morning Posters	44	Tuesday Afternoon Talks	267
Saturday Afternoon Talks	77	Tuesday Afternoon Posters	275
Saturday Afternoon Posters	84	Wednesday Morning Talks	309
Sunday Morning Talks	116	Wednesday Morning Posters	316
Sunday Morning Posters	123	Topic Index	336
Sunday Afternoon Talks	158	Author Index	339
Sunday Afternoon Posters	165		



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Sessions Overview

Member-Initiated Symposia	4	Saturday Afternoon Posters	84
Schedule Overview	4	Color and light: Adaptation and constancy	84
S1 Mechanisms of adaptation in different visual cortical areas: electrophysiology, functional imaging and computational modeling.	4	Multisensory processing: Visual, tactile and vestibular interactions.	88
S2 Models of Perceptual Learning: Combining Psychophysics, Computation and Neuroscience	5	Perceptual organization: Contours and surfaces	91
S3 Perception of Emotion from Body Expression: Neural basis and computational mechanisms	6	Attention: Endogenous and exogenous.	95
S4 Ongoing fluctuation of neural activity and its relationship to visual perception.	8	Attention: Features and objects.	98
S5 Prediction in Visual Processing.	9	Noise and uncertainty	103
S6 Integrating local motion information.	10	Motion: Neural mechanisms	105
Friday Evening Posters.	13	Spatial vision: Mechanisms	108
Eye movements: Cognition and scenes	13	Spatial vision: Encoding and decoding	111
Object recognition: Neural mechanisms	18	Sunday Morning Talks	116
Visual memory: Objects and features.	22	Motion: Encoding and aftereffects	116
Attention: Neural mechanisms I.	25	Object recognition: Features	117
Attention: Inattention and attention blindness.	29	Multisensory processing	119
Color and light: Lightness and brightness.	30	Attention: Neural mechanisms and reward	121
Perceptual learning: Plasticity and adaptation.	33	Sunday Morning Posters	123
Saturday Morning Talks	36	Eye movements: Perisaccadic perception	123
Color and light: Surfaces and materials.	36	Development: Childhood and infancy.	125
Attention: Features and objects.	37	Development: Amblyopia	128
Spatial vision: Crowding	39	Face perception: Expression and emotion.	130
Perceptual learning: Transfer and specificity	41	Face perception: Experience and learning.	133
Saturday Morning Posters	44	Perception and action: Reaching and grasping	137
Eye movements: Saccades and fixations	44	Scene perception: Memory and context.	141
Visual search: Eye movements	48	Attention: Capture	144
Binocular vision: Binocular combination and rivalry	50	Motion: Flow, depth, and spin	147
3D perception: Contours, shading and texture.	53	3D perception: Dynamic cues	151
Attention: Tracking.	56	Temporal processing.	153
Visual memory: Encoding and retrieval	60	Sunday Afternoon Talks	158
Motion: Biological motion	64	Perceptual organization	158
Face perception: Wholes and parts.	68	Visual memory	159
Face perception: Disorders	71	Spatial vision: Natural images	161
Perception and action: Pointing and hitting	74	Face perception: Neural mechanisms	163
Saturday Afternoon Talks	77	Sunday Afternoon Posters	165
Development: Infancy and childhood	77	Color and light: Memory, language and synesthesia	165
Eye movements: Remapping.	78	Binocular vision: Binocular rivalry and awareness	169
Perception and action: Navigation and locomotion	80	Perception and action: Navigation and wayfinding	171
Object recognition: Parts and categories	82	Perception and action: Neural Mechanisms	173
		Multisensory processing: Visual-auditory interactions	175
		Attention: Neural mechanisms II	179
		Attention: Models	183
		Perceptual learning: Models	184
		Perceptual learning: Neural mechanisms	187
		Eye movements: Pursuit and following.	190
		Motion: Local mechanisms and models.	193

Monday Morning Talks	198	Tuesday Afternoon Talks	267
Development: Disorders	198	Spatial vision: Neural and psychophysical mechanisms	267
Attention: Spatial selection and modulation.	199	Attention: Temporal and capture	269
Color and light: Mechanisms.	201	Perception and action: Pointing, hitting, reaching, and grasping.	271
Perceptual learning: Models and neural mechanisms	203	Motion: Integration	272
Monday Morning Posters	206	Tuesday Afternoon Posters	275
Perceptual organization: Shapes and objects	206	Face perception: High-level features	275
Attention: Temporal	210	Development: Face perception	279
Eye movements: Methods and gaze	212	Visual search: Natural scenes and practical tasks	282
Binocular vision: Eye movements.	216	Visual search: Neural mechanisms.	285
Face perception: Features and configuration	218	3D perception: Natural and virtual scenes	287
Face perception: Neural mechanisms	221	Scene perception: Features and categories	290
Tuesday Morning Talks	226	Development: Disorders	294
3D perception.	226	Object recognition: Categories	297
Eye Movements: Mechanisms, methods and models	227	Object recognition: Features	301
Binocular vision.	229	Attention: Divided	306
Face perception: Cognitive factors	231	Wednesday Morning Talks	309
Tuesday Morning Posters	234	Temporal processing.	309
Attention: Spatial selection and modulation.	234	Face perception: Parts and wholes	310
Perceptual organization: Segmentation and grouping	240	Object recognition and scene perception: Neural mechanisms	312
Attention: Shifting.	244	Visual search	314
Visual search: Elements, cues and configurations	246	Wednesday Morning Posters	316
Perceptual learning: Transfer and specificity	251	Motion: Higher-order, objects, and illusions	316
Perception and action: Locomotion	253	Perceptual organization: Mechanisms and models	319
Object recognition: Experience and learning	258	Visual memory: Capacity and resolution	322
Spatial vision: Summary statistics	261	Attention: Emotion	327
Spatial vision: Crowding and eccentricity.	262	Attention: Reward.	329
		Binocular vision: Stereopsis.	330
		Development: Lifespan and aging	333
		Topic Index	337
		Author Index.	339

Abstract Numbering System

Each abstract is assigned a unique 4 to 5 digit number based on when and where it is to be presented. The format of the abstract numbering is DT.RN (where D is the Day, T is the Time, R is the Room and N is the Presentation number).

First Digit - Day	Second Digit - Time Period	Third Digit - Room	Fourth/Fifth Digits - Number
1 Friday	1 Early AM talk session	1 Royal Palm 1-3	1, 2, 3... For talks
2 Saturday	2 Late AM talk session	2 Royal Palm 4-5	01, 02, 03... For posters
3 Sunday	3 AM poster session	3 Royal Palm 6-8	
4 Monday	4 Early PM talk session	4 Orchid Ballroom	
5 Tuesday	5 Late PM talk session	5 Vista Ballroom	
6 Wednesday	6 PM poster session		

Examples:

21.16 Saturday, early AM talk in Royal Palm 1-3, 6th talk
 36.513 Sunday, PM poster in Vista Ballroom, poster board 513
 53.306 Tuesday, AM poster in Royal Palm 6-8, poster board 306

Note: Two digits after the period indicates a talk, three digits indicates a poster (and is also the number of the poster board).

Member-Initiated Symposia

Schedule Overview

Friday, May 7, 12:00 – 2:00 pm

S1 Mechanisms of adaptation in different visual cortical areas: electrophysiology, functional imaging and computational modeling, Royal Palm Ballroom 1-3

S2 Models of Perceptual Learning: Combining Psychophysics, Computation and Neuroscience, Royal Palm Ballroom 4-5

S3 Perception of Emotion from Body Expression: Neural basis and computational mechanisms, Royal Palm Ballroom 6-8

Friday, May 7, 2:30 – 4:30 pm

S4 Ongoing fluctuation of neural activity and its relationship to visual perception, Royal Palm Ballroom 1-3

S5 Prediction in Visual Processing, Royal Palm Ballroom 4-5

S6 Integrating local motion information, Royal Palm Ballroom 6-8

S1

Mechanisms of adaptation in different visual cortical areas: electrophysiology, functional imaging and computational modeling

Friday, May 6, 12:00 - 2:00 pm, Royal Palm 1-3

Organizer: Rufin Vogels, Department Neuroscience, K.U. Leuven Medical School, Leuven, Belgium

Presenters: Adam Kohn, Department of Neuroscience, Albert Einstein College of Medicine, New York; Rufin Vogels, Department Neuroscience, K.U. Leuven Medical School, Leuven, Belgium; Kalanit Grill-Spector, Department of Psychology & Neurosciences Institute, Stanford University; Stephen J. Gotts, Laboratory of Brain and Cognition, NIMH/NIH, Bethesda

Symposium Description

Neural responses in many visual areas are usually reduced when repeating a visual stimulus. This adaptation or repetition suppression effect has recently aroused considerable interest because of the use of fMRI-adaptation to infer stimulus selectivities or invariances of neuronal populations in humans. The use of fMRI-adaptation necessitates an understanding of the mechanisms of adaptation. Given the increased use of fMRI-adaptation, we believe it is time to review our current understanding of the mechanisms of adaptation and their implications for the interpretation of functional imaging adaptation data. In the proposed symposium we will discuss experiments and computational work that provided new insights into the neural mechanisms of adaptation. Importantly, we will compare adaptation mechanisms in different visual areas in non-human and human primates. In addition, we will address adaptation effects of different neural measures, i.e. spiking activity, local field potentials and fMRI, and integrate these experimental data with recent computational work. We will have 4 speakers, giving each 30-minute talks (including 5 minutes of discussion time). Adam Kohn (Albert Einstein College of Medicine) will present his recent work on adaptation mechanisms in macaque primary visual cortex using microelectrode array recordings of populations of single neurons. These new data on orientation tuning and contrast sensitivity demonstrate a rich variety of adaptation effects which can be explained by a simple computational model, reconciling previous findings of effects of adaptation on tuning in areas V1 and MT. The second speaker, Rufin Vogels (K.U. Leuven), will review

the effects of adaptation on the shape tuning of macaque inferior temporal cortex. He will compare adaptation effects of spiking activity and local field potentials (LFPs) and test predictions of different models of adaptation. The spiking activity and LFPs adaptation data agreed with input-dependent, but not response-dependent neural fatigue models. Kalanit Grill-Spector (Stanford University) will examine different models of adaptation using high-resolution fMRI in human ventral temporal cortex. She will compare adaptation effects in different ventral regions and across different adaptation paradigms in relation to predictions from different neural models of adaptation. These fMRI data suggest that different adaptation mechanisms underlie fMRI-adaptation in different brain regions and may differ between paradigms. The fourth speaker, Stephen Gotts (NIMH), will review computational work on adaptation mechanisms and relate these to physiological work in the macaque and human MEG and intracranial EEG recordings. This work suggests the need to consider synchronization of neural activity in addition to changes in the response level. It also links the behavioral improvement in performance with repetition to neural adaptation mechanisms.

The multi-region and multi-technique approach makes the proposed symposium rather unique and original. The symposium is of obvious interest to visual neuroscientists -students and faculty - and given the link between neural adaptation and perceptual aftereffects and repetition priming, this topic will also be of interest to visual psychophysicists. The attendees will gain insights into mechanisms of adaptation, which are crucial for interpreting fMRI-adaptation results and linking these with behavioral effects of stimulus repetition.

Presentations

The influence of surround suppression on adaptation effects in primary visual cortex

Adam Kohn, Department of Neuroscience, Albert Einstein College of Medicine, New York

Adaptation has been used extensively to probe mechanisms of visual processing. Neurophysiological studies have measured how adaptation affects single neurons, using stimuli tailored to evoke robust responses.

Understanding the consequences of adaptation, however, requires measuring effects on neural populations, which include many cells that are weakly driven by the adapter. To provide a more complete view of how adaptation affects neural responses, we implanted microelectrode arrays in primary visual cortex of macaque monkeys and measured orientation tuning and contrast sensitivity before and after prolonged adaptation with a range of stimuli. Whereas previous studies have emphasized that adaptation suppresses responsiveness and repels tuning (termed, stimulus-specific suppression), we find that adaptation can also lead to response facilitation and attractive shifts in V1 tuning. Using a simple computational model, we show that which of these effects occurs depends on the relative drive provided by the adapter to the receptive field and suppressive surround. Our data reveal a richer repertoire of adaptation effects than previously considered and provide a simple explanation for previously disparate findings concerning the effects of adaptation on tuning in V1 and MT. More generally, our results suggest an intimate relationship between spatial and temporal contextual effects, with implications for interpreting fMRI data and for understanding the functional role of rapid sensory-driven plasticity.

Mechanisms of adaptation of spiking activity and local field potentials in macaque inferior temporal cortex

Rufin Vogels, Department Neuroscience, K.U. Leuven Medical School, Leuven, Belgium

Several neural models have been proposed to explain adaptation effects in visual areas. We compared predictions derived from these models with adaptation effects of spiking activity and Local Field Potentials (LFPs) in macaque inferior temporal (IT) cortex. First, we compared the effect of brief adaptation on shape tuning using parameterized shape sets with predictions derived from fatigue and sharpening models. We found adaptation of spiking activity and of LFP power in the high-gamma (60-100 Hz) band. Contrary to sharpening but in agreement with fatigue models, repetition did not affect shape selectivity. The degree of similarity between adapter and test shape was a stronger determinant of adaptation than was the response to the adapter. The spiking and LFP adaptation effects agreed with input-, but not response-fatigue models. Second, we examined whether stimulus repetition probability affects adaptation, as predicted from the top-down, perceptual expectation model of Summerfield et al. (Nat. Neurosci., 2008). Monkeys were exposed to 2 interleaved trials, each consisting of 2 either identical (rep trial) or different stimuli (alt trial). Repetition blocks consisted of 75% (25%) of rep (alt) trials and alternation blocks had the opposite repetition probabilities. For both spiking and LFP activities, adaptation did not differ between these blocks. This absence of any repetition probability effect on adaptation suggests that adaptation in IT is not caused by contextual factors related to perceptual expectation, but instead agrees with bottom-up, fatigue-like mechanisms. We will discuss the implications of these single unit and LFP data for the interpretation of fMRI-adaptation studies.

fMRI-Adaptation in Human Ventral Temporal Cortex: Regional Differences Across Time Scales

Kalanit Grill-Spector, Dept. of Psychology & Neurosciences Institute, Stanford University

One of the most robust experience-related cortical dynamics is reduced neural activity when stimuli are repeated. This reduction has been linked to performance improvements due to repetition and also used to probe functional characteristics of neural populations. However, the underlying neural mechanisms are as yet unknown. Here, we consider two models that have been proposed to account for repetition-related reductions in neural activity, and evaluate them in terms of their ability to account for the main properties of this phenomenon as measured with fMRI (referred to as fMRI-adaptation, fMRI-A). I will describe results of recent experiments in which we investigated the effects of short-lagged (SL, immediate) and long-lagged (LL, many intervening stimuli) repetitions on category selectivity in human ventral temporal cortex (VTC) using high-resolution fMRI. We asked whether repetition produces scaling or sharpening of fMRI responses across VTC. Results illustrate that repetition effects across time scales vary qualitatively along a lateral-medial axis. In lateral VTC, both SL and LL repetitions produce scaling of fMRI responses. In contrast, medial VTC exhibits scaling effects during SL repetitions, but sharpening effects for LL repetitions. Finally, computer simulations linking neural repetition effects to fMRI-A show that different neural mechanisms likely underlie fMRI-A in medial compared to lateral VTC. These results have important implications for future fMRI-A experiments because they suggest that fMRI-A does not reflect a universal neural mechanism and that results of fMRI-A experiments will likely be paradigm independent in lateral VTC, but paradigm dependent in medial VTC.

Mechanisms of repetition suppression in models, monkeys, and humans: A case for greater efficiency through enhanced synchronization

Stephen J. Gotts, Laboratory of Brain and Cognition, NIMH/NIH, Bethesda Experience with visual objects leads to later improvements in identification speed and accuracy ("repetition priming"), but generally leads to reductions in neural activity in single-cell recording studies in monkeys and fMRI studies in humans ("repetition suppression"). While the cell mechanisms that lead to these activity reductions are unclear, previous studies have implicated relatively local, automatic cortical mechanisms, and slice physiological recordings have identified several candidate short- and long-term plasticity mechanisms. I will show that these plasticity mechanisms when incorporated into a simplified neocortical circuit model are capable of re-producing changes in stimulus selectivity due to repetition as seen in single-cell recording studies in monkey area TE: "scaling" with relatively short-term repetitions and "sharpening" over longer periods of experience. However, these simulations when based on average firing rate fail to provide an account of behavioral priming. In contrast, simulations that retain

the spiking property of neurons can potentially account for both repetition suppression and priming by allowing more synchronized and temporally coordinated activity at lower overall rates. I will review the current state of evidence in support of this proposal from monkey single-cell and LFP recordings and human MEG. I will also present new data from intracranial EEG recordings of human epilepsy patients showing that stimulus repetition at both short and long time scales leads to larger amplitude activity fluctuations at low frequencies (< 15 Hz). These results indicate that greater neural synchronization accompanies lower overall activity levels following stimulus repetition, constituting a novel efficiency mechanism.

S2

Models of Perceptual Learning: Combining Psychophysics, Computation and Neuroscience

Friday, May 6, 12:00 - 2:00 pm, Royal Palm 4-5

Organizer: Alexander A. Petrov, Department of Psychology, Ohio State University

Presenters: Zhong-Lin Lu, Department of Psychology, University of Southern California; Alexander A. Petrov, Department of Psychology, Ohio State University; Joshua Gold, Department of Neuroscience, University of Pennsylvania; Peggy Series, Institute for Adaptive and Neural Computation, University of Edinburgh; Dov Sagi, The Weizmann Institute of Science, Israel

Symposium Description

Perceptual learning refers to improvements in perceptual abilities through training. It has been a topic of growing interest over the last two decades. Perceptual learning is a valuable tool for studying the organization of the visual system and the mechanisms of brain plasticity. It also has a great potential for practical applications such as training of visual experts and rehabilitation of persons with disabilities. These challenges are complex and require an integrated, multidisciplinary approach. There is a wealth of behavioral data documenting the occurrence, speed, specificity, and other properties of perceptual learning under various conditions. There is also a growing stream of human neuroimaging and animal neurophysiological data. What continues to elude the field, however, is an integrated theoretical understanding of these disparate findings. Computational and mathematical modeling is an important tool in this regard. Models help us formulate explicit and consistent principles and mechanisms, generate novel predictions, and bridge the explanatory gap between brain and behavior. A number of models of perceptual learning with increasing scope and sophistication have been developed in recent years.

This symposium brings together an international panel of experts in perceptual learning, with particular emphasis on computational and/or formal approaches. These speakers have made important contributions to the field of perceptual learning using a mixture of psychophysical, computational, and neuroscientific approaches. Here they will each present computational models of perceptual learning that advance our understanding of the underlying brain mechanisms. Zhong-Lin Lu will start with a broad overview of the functions and mechanisms. Alex Petrov will explore one particular mechanism -- selective reweighting -- in some detail. Joshua Gold will present a novel analytical model of population coding that allows us to quantify how various changes in neuronal firing rates can affect perceptual performance. Peggy Series will present a reweighting account for patterns of disruption and transfer of perceptual learning for visual hyperacuity. Finally, Dov Sagi will discuss some unexpected consequences of the hypothesis that perceptual learning involves statistical modeling of the task at hand.

The symposium is designed to serve both as a tutorial of established ideas and techniques and as a venue to introduce new advances at the cutting edge of this active research area. Perceptual learning is a field of investigation that impacts all aspects of vision and thus this symposium will interest VSS attendees across disciplines and at all levels, from students to experts. An earlier symposium on perceptual learning attracted an audience beyond room capacity at VSS 2006. The current proposal builds on this success by adding an emphasis on modeling and reporting the exciting new developments in the intervening years.

Presentations

Functions and Mechanisms of Perceptual Learning

Zhong-Lin Lu, Department of Psychology, University of Southern California

Perceptual learning -- the improvement of performance through practice or training -- has been observed over a wide range of perceptual tasks in adult humans. The high degree of plasticity of the adult perceptual systems suggests that perception and perceptual learning cannot be studied separately. In this talk, we will review some major functions and mechanisms of perceptual learning, including specificity of perceptual learning, the law of practice in perceptual learning, mechanisms of perceptual learning, the level and mode of perceptual learning, optimal training procedures, and computational models of perceptual learning. Studies of these various aspects of perceptual learning have greatly enhanced our understanding of the information processing limitations of the human observer, and how the state of the observer changes with training, with strong implications for the development of potential noninvasive training methods for perceptual expertise in normal populations and for the amelioration of deficits in challenged populations.

A Selective-Reweighting Model of Perceptual Learning

Alexander A. Petrov, Department of Psychology, Ohio State University

Growing evidence suggests that selective reweighting of the read-out connections from the sensory representations plays a major role in perceptual learning. Here we instantiate this idea in a computational model that takes grayscale images as inputs and learns on a trial-by-trial basis. The model develops the multi-channel perceptual template model (PTM, Doshier & Lu, 1998, PNAS) and extends it with a biologically plausible learning rule. The stimuli are processed by standard orientation- and frequency-tuned representational units, divisively normalized. Learning occurs only in the read-out connections to a decision unit; the stimulus representations never change. An incremental Hebbian rule tracks the task-dependent predictive value of each unit, thereby improving the signal-to-noise ratio of their weighted combination. Each abrupt change in the environmental statistics induces a switch cost in the learning curves as the system temporarily works with suboptimal weights. In this situation, self-generated feedback seems sufficient for learning. The model accounts for a complex pattern of context-induced switch costs in a non-stationary training environment.

A recent study (Petrov & Hayes, 2010, JOV) found a strongly asymmetric pattern of transfer of learning between first- and second-order motion. Second-order training transferred fully to first-order test, whereas first-order training did not transfer significantly to second-order. This strong asymmetry challenges the simple reweighting model but is compatible with an augmented version in which the Fourier and non-Fourier processing channels are integrated by taking the maximum of the carrier-specific signals within a given direction of motion.

A neural-coding theory of perceptual learning-related plasticity

Joshua Gold, Department of Neuroscience, University of Pennsylvania; Ching-Ling Teng, University of Virginia, Chi-Tat Law, Stanford University

A striking feature of perceptual learning is the diversity of neural mechanisms that have been implicated in different studies. For example, some forms of perceptual learning appear to involve changes in how sensory information is represented in early sensory areas of the brain. In contrast, other forms appear to involve improved read-out of information from unchanged sensory representations. Little is known about the principles that govern when these different forms of plasticity occur. Here we propose and test the theory that these different forms of plasticity represent the most effective ways to optimize task performance under different conditions. We test this idea using a novel analytical model of population cod-

ing that allows us to quantify how various changes in properties of a sensory representation and its readout can affect perceptual performance. The results indicate that diverse neural mechanisms of perceptual learning can reflect common principles of task optimization.

Disruption and Transfer of Perceptual Learning for Visual Hyperacuity

Peggy Series, Institute for Adaptive and Neural Computation, University of Edinburgh; Grigorios Sotiropoulos, University of Edinburgh; Aaron Seitz, University of California at Riverside

Improvements of visual hyperacuity are a key focus in research of Perceptual Learning. Of particular interest has been the specificity of visual hyperacuity learning to the particular features of the trained stimuli as well as disruption of learning that occurs in some cases when different stimulus features are trained together. The implications of these phenomena on the underlying learning mechanisms are still open to debate; however, there is a marked absence of computational models that explore these phenomena in a unified way. Here we present a computational learning model based on reweighting and extend it to enable direct comparison, by means of simulations, with a variety of psychophysical data. We find that this very simple model can account for several findings, such as disruption of learning of one task by practice on a similar task, as well as transfer of learning across both tasks and stimulus configurations under certain conditions. These simulations help explain existing results in the literature as well as provide important insights and predictions regarding the reliability of different hyperacuity tasks and stimuli.

Perceptual learning viewed as a statistical modeling process -- Is it all overfitting?

Dov Sagi, The Weizmann Institute of Science, Israel; Hila Harris, The Weizmann Institute of Science, Israel

Performance gains obtained through perceptual learning are, surprisingly, specific to the trained condition. Recent research shows that specificity increases with training and with task precision (Jeter et al. 2009/10), and generalizes across tasks and features trained in temporal proximity (Yu and colleagues). Such results are expected if perceptual learning involves statistical modeling of the task at hand, with variations in brain anatomy (Mollon & Danilova, 1996), or neuronal response, limiting the reliability of the fitted data. When training is carried out with a limited set of stimuli (e.g. a single contrast), overfitting may gradually arise, thus predicting failures when new conditions are presented. In the contrast domain, learning is specific to the trained contrast, and much reduced when different contrasts are mixed during training (Adini et al. 2004; Yu et al., 2004), demonstrating that learning is nothing but overfitting. Overfitting may arise when learning involves the readout of sensory neurons (Lu & Doshier), reweighting responses according to the peculiarities of the trained condition. To test the generality of this theoretical approach, we re-examined the specificity of learning to retinal location. Using the texture discrimination task (Censor & Sagi, 2009), we had observers practicing a target positioned either at a fixed location (the traditional way) or at one of two locations. Against overfitting, we find equal learning in both conditions, but most surprisingly, in agreement with overfitting, while the 1-location training was specific as expected, the 2-locations training completely transferred to locations previously untrained, nor tested. Theoretical implications will be presented.

S3

Perception of Emotion from Body Expression: Neural basis and computational mechanisms

Friday, May 6, 12:00 - 2:00 pm, Royal Palm 6-8

Organizer: Martin A. Giese, Hertie Institute for Clinical Brain Research, CIN, Tübingen, Germany

Presenters: Maggie Shiffrar, Dept. of Psychology, Rutgers University, Newark, NJ; Beatrice de Gelder, Dept. of Psychology, University of Tilburg, NL; Martin Giese, Hertie Inst. f. Clinical Brain Research, CIN, Tübingen, Germany; Tamar Flash, Weizmann Institute of Science, Rehovot, IL

Symposium Description

In a world constantly in flux, we are faced with uncertainty about the expression of emotion by body postures and movements is highly relevant in social communication. However, only recently this topic has attracted substantial interest in visual neuroscience. The combination of modern approaches for stimulus generation by computer graphics, psychophysics, brain imaging, research on patients with brain damage, and novel computational methods have revealed interesting novel insights in the processing of these complex visual stimuli. The combination of experimental techniques with different computational approaches, including ones from computational vision, has revealed novel insights in the critical visual features for the perception of emotions from bodily expressions. Likewise, such approaches have provided novel insights in the relationship between visual perception and action generation, and the influence of attention on the processing of such stimuli. The symposium brings together specialists from different fields who have studied the perception of emotional body expressions with complementary methodologies. This work has revealed the importance of affective signals conveyed the whole body, in addition and beyond the well-studied channel of static facial expressions. The first talk by M. Shiffrar presents work that investigates the perception of threats from body stimuli. The second contribution by B. de Gelder will discuss experiments showing that the perception of emotion from bodies is still possible without visual awareness, potentially involving subcortical visual structures. These experiments include functional imaging studies and studies in patients. The contribution by M. Giese presents several examples how a combination of psychophysical experiments and statistical techniques from machine learning is suitable for the identification of critical visual features that are essential for the recognition of emotions of interactive and non-interactive body movements. Finally, the contribution of T. Flash shows evidence from psychophysical and imaging experiments that supports the hypothesis that the visual system is tuned to the perception of spatio-temporal invariants that are common, specifically, to emotional body movements. Summarizing, the symposium will present examples for a novel approach for the study of complex visual mechanism that provide a basis for the quantitative and well-controlled study of the visual processing of complex social signals. Such work will be interesting for a broad spectrum of VSS visitors, including faculty, researcher and students. The topic should be of particular interest to visitors from high-level vision, face / body and motion perception.

Presentations

The perception of bodily threats

Maggie Shiffrar, Dept. of Psychology, Rutgers University, Newark, NJ

Numerous results indicate that observers are particularly sensitive to angry and fearful faces. Such heightened sensitivity supports the hypothesis that observers are best able to detect potentially harmful information. Because bodily cues to threat can be seen from farther away, the goal of our work is to determine whether observers demonstrate enhanced visual sensitivity to body signaling different types of threat. One set of studies consisted of a modified "face in a crowd" paradigm in which observers viewed arrays of body postures depicting various emotional states. All emotional expressions were applied to the same generic male body with a neutral facial expression. Body postures were normed for perceived emotional content. Participants sequentially viewed circular arrays of 6 emotional body postures and reported with a key press whether or not each array contained a different or oddball body posture. Consistent with the threat advantage hypothesis, observers demonstrated speeded detection of threatening body postures. Another series of studies investigated a more subtle type of threat detection. Previous work has shown that women preferentially attend to thin bodies. We investigated whether this effect is specific to women looking at other women's bodies. Using a dot probe paradigm, the strongest

attentional bias was found with women looking at women's bodies. Bias magnitude correlated positively with each observer's level of dissatisfaction with her own body. To the extent that women compare their own bodies with observed bodies, this effect also conforms to the threat advantage hypothesis. This research was supported by NSF grant EXP-SA 0730985 and the Simons Foundation (grant 94915).

Perceiving bodily expressions with or without visual awareness

Beatrice de Gelder, Dept. of Psychology, University of Tilburg, NL

Bodily expressions of emotion are powerful signals regulating communicative exchanges. For better or worse, we spend our life surrounded by other people. Nothing is less surprising than to assume that we are trained and over-trained to read their body language. When we see someone running with the hands protecting his face we perceive at once the fear and the action of running for cover. We rarely hesitate to assign meaning to such behaviors, and we do not wait to recognize fight behavior till we are close by enough to see the person's facial expression. Here we report on new findings concerning the role of attention and of visual awareness on the perception and neurofunctional basis of our ability to recognize bodily expressions. Our experiments show that briefly seen, but also consciously unseen bodily stimuli may induce an emotional state and trigger adaptive actions in the observer. Exposure to unseen emotional stimuli triggers activity in the cortical and subcortical visual system and is associated with somatic changes typical of emotions. Specifically, unattended but also non-consciously perceived emotional body expressions elicit spontaneous facial expressions and psychophysiological changes that reflect the affective valence and arousal components of the stimuli. Similar results are also obtained in neurologically intact subjects in whom blindsight-like effects are induced by visual masking. Moreover, participants facial reactions are faster and autonomic arousal is higher for unseen than for seen stimuli. We will discuss the implications of these findings for current debates in human emotion theories.

Features in the perception of interactive and non-interactive bodily movements

Martin Giese, Hertie Inst. f. Clinical Brain Research, CIN, Tübingen, Germany

Body postures and movements provide important information about affective states. A variety of existing work has focused on the characterization of the perception of emotions from bodies and point-light motion, often using rather qualitative or heuristic methods. Recent advances in computational learning and computer animation have opened novel possibilities for the well-controlled study of emotional signals conveyed by the human body and their visual perception. In addition, almost no quantitative work exists on the features that underlie the perception of emotions conveyed by the body during interactive behavior. Using motion capture combined with a mood induction paradigm, we studied systematically the expression and perception of emotions expressed by interactive and non-interactive movements. Combining methods from machine learning with psychophysical experiments we characterize the kinematic features that characterize emotional movements and investigate how they drive the visual perception of emotions from the human body.

Invariants common to perception and action in bodily movements

Tamar Flash, Weizmann Institute of Science, Rehovot, IL

Behavioral and theoretical studies have focused on identifying the kinematic and temporal characteristics of various movements ranging from simple reaching to complex drawing and curved motions. These kinematic and temporal features have been quite instrumental in investigating the organizing principles that underlie trajectory formation. Similar kinematic constraints play also a critical role in the visual perception of abstract and biological motion stimuli, and in visual action recognition. To account for these observations in the visual perception and production of body motion we present a new model of trajectory formation inspired by geometrical invariance. The model proposes that movement duration, timing, and compositionality arise from cooperation among several geometries. Different geometries possess different measures of distance. Hence, depending on the selected geometry, movement duration is proportional to the corresponding distance parameter. Expressing these ideas mathematically, the model has led to concrete predictions concerning the kinematic and temporal features of both drawing and locomotion trajectories. The model has several important implications with respect to action observation and recognition

and the underlying brain representations. Some of these implications were examined in a series of fMRI studies which point to the importance of geometrical invariances and kinematic laws in visual motion processing.

S4

Ongoing fluctuation of neural activity and its relationship to visual perception

Friday, May 6, 2:30 - 4:30 pm, Royal Palm 1-3

Organizer: Hakwan Lau, Columbia University, Donders Institute, Netherlands

Presenters: Biyu Jade He, National Institute of Health; Charles Schroeder, Nathan S. Kline Institute for Psychiatric Research, Columbia University; Andreas Kleinschmidt, INSERM-CEA, NeuroSpin, Gif/Yvette, France; Hakwan Lau, Columbia University, Donders Institute, Netherlands; Tony Ro, City University of New York

Symposium Description

Even in the absence of external stimulation, the visual system shows ongoing fluctuations of neural activity. While some early theoretical analyses suggest that the impact of such fluctuations in activity on visual perception may be minimal, recent empirical results have given new insights on this issue. We will review this evidence and the new theoretical perspectives in this symposium. Below are a few key themes:

- Coverage of multiple experimental methods and fluctuations in activity at different time scales:

The 5 speakers will discuss experiments that employ different methods to measure ongoing fluctuations in neural activity, such as human fMRI (functional magnetic resonance imaging) in patients and healthy subjects, intracranial cortical EEG (electroencephalography) in presurgical epileptics, combined use of TMS (transcranial magnetic stimulation) and optical imaging, and electrophysiological studies in non-human primates. These methods investigate fluctuations in neural activity at different time scales, from 10-20 seconds per cycle to the sub-second oscillatory range. The relationship between these different activities will be discussed.

- What ongoing activities tell us about the mechanisms of attention?

In addition to discussing the nature of ongoing activity and its impact on perception, several speakers will also use ongoing activity as a tool to understand the basic mechanisms of attention and awareness.

- Implication for clinical studies of perception:

Several speakers will discuss data collected from presurgical epileptics, where intracranial cortical EEG data were recorded. The nature of ongoing fMRI activity in patients suffering from strokes will also be discussed.

- Debate of theoretical perspectives and interpretations of data:

The different speakers will present competing theoretical perspectives on the nature of ongoing activity, as well as alternative interpretations of the same results. This will promote an exchange of ideas and hopefully lead to consensus on and illumination of the issues.

The nature of ongoing neural activity and its relationship to perception should be relevant to all attendants of VSS. We aim to have a broad audience, as we will be covering different experimental paradigms with different empirical methods. We expect the symposium to be especially interesting for researchers specializing in attention and awareness. Also, although the topic is primarily on neural activity, one focus of the symposium is its relationship to behavior. Hence some speakers will also present behavioral studies inspired by the investigation of ongoing neural activity, which

will be of interests to many. Specifically, in some talks the implications of our understanding of ongoing neural activity and issues of experimental design will be discussed.

Presentations

Spontaneous fMRI signals and slow cortical potentials in perception

Biyu Jade He, National Institute of Health

The brain is not a silent, complex input/output system waiting to be driven by external stimuli; instead, it is a closed, self-referential system operating on its own with sensory information modulating rather than determining its activity. Ongoing spontaneous brain activity costs the majority of the brain's energy budget, maintains the brain's functional architecture, and makes predictions about the environment and the future. I will discuss some recent research on the functional significance and the organization of spontaneous brain activity, with implications for perception research. The past decade has seen rapid development in the field of resting-state fMRI networks. In one of the first studies that established the functional significance of these networks, we showed that strokes disrupted large-scale networks in the spontaneous fMRI signals, and that the degree of such disruption predicted the patients' behavioral impairment (spatial neglect). Next, we identified the neurophysiological signal underlying the coherent patterns in the spontaneous fMRI signal, the slow cortical potential (SCP). The SCP is a novel neural correlate of the fMRI signal; existing evidence suggests that it most likely underlies both spontaneous fMRI signals and task-evoked fMRI responses. I further discuss some existing data suggesting a potential involvement of the SCP in conscious awareness, including the influence of spontaneous SCP fluctuations on visual perception. Lastly, given that both the SCP and the fMRI signal display a power-law distribution in their temporal power spectra, I argue that the role of scale-free brain activity in perception and consciousness warrants future investigation.

Tuning of the neocortex to the temporal dynamics of attended event streams

Charles Schroeder, Nathan S. Kline Institute for Psychiatric Research, Columbia University

When events occur in rhythmic streams, attention may use the entrainment of neocortical excitability fluctuations (oscillations) to the tempo of a task-relevant stream, to promote its perceptual selection, and its representation in working memory. To test this idea, we studied humans and monkeys using an auditory-visual stream selection paradigm. Electrooculogram (ECoG) activity sampled from subdural electrodes in epilepsy patients showed that: 1) attentional modulation of oscillatory entrainment operates in a network of areas including auditory, visual, posterior parietal, inferior motor, inferior frontal, cingulate and superior midline frontal cortex, 2) strength of oscillatory entrainment depends on the predictability of the stimulus stream, and 3) these effects are dissociable from attentional enhancement of evoked activity. Fine-grained intracortical analysis of laminar current source density profiles and concomitant neuronal firing patterns in monkeys showed that: 1) along with responses "driven" by preferred modality stimuli (e.g., visual stimuli in V1), attended non-preferred modality stimuli (e.g., auditory stimuli in V1) could "modulate" local cortical excitability by entraining ongoing oscillatory activity, 2) while this "heteromodal" entrainment occurred in the extragranular layers, the granular layers remain phase-locked to the stimulus stream in the preferred modality. Thus, attention may use phase modulation (coherence vs opposition) to control the projection of information from input to output layers of cortex. On a regional scale, oscillatory entrainment across a network of brain regions may provide a mechanism for a sustained and distributed neural representation of attended event patterns, and for their availability to working memory.

Probing Perceptual Consequences of Ongoing Activity Variations

Andreas Kleinschmidt, INSERM-CEA, NeuroSpin, Gif/Yvette, France

Recordings of ongoing brain activity show remarkable spontaneous fluctuations such that detecting stimulus-driven responses usually requires multiple repetitions and averaging. We have assessed the functional impact of such fluctuations on evoked neural responses and human perceptual performance. We studied human participants using functional neuroimaging and sparse event-related paradigms with sensory probes that could be either ambiguous with respect to perceptual categories (faces) or peripheral for a given feature (visual motion coherence). In both instances, fluct-

tuations in ongoing signal of accordingly specialized brain regions (FFA, hMT+) biased how upcoming stimuli were perceived. Moreover, the relation between evoked and ongoing activity was not simply additive, as previously described in other settings, but showed an interaction with perceptual outcome. This latter observation questions the logic of event-related averaging where responses are thought to be unrelated from the level of pre-stimulus activity. We have further analyzed the functional connotation of the imaging signal by analyzing false alarm trials. Counter the notion of this signal being a proxy of sensory evidence, false alarms were preceded by especially low signal. A theoretical framework that is compatible with our observations comes from the family of predictive coding models, the 'free energy' principle proposed by Karl Friston. Together, our findings illustrate the functional consequences of ongoing activity fluctuations and underline that they should not be left unaccounted for as in the traditional mainstream of data analysis.

The paradoxical negative relationship between attention-related spontaneous neural activity and perceptual decisions

Hakwan Lau, Columbia University, Donders Institute, Netherlands;
Dobromir Rahnev, Columbia University

One recent study reported that when ongoing pre-stimulus fMRI activity in the dorsal attention network was high, the hit rate in an auditory detection task was surprisingly low. This result is puzzling because pre-stimulus activity in the dorsal attention network presumably reflects the subjects' attentional state, and high attention is supposed to improve perception, not impair it. However, it is important to distinguish between the capacity and decision/criterion aspects of perception. Using signal detection theoretic analysis, we provide empirical evidence to show that spatial attention can lead to conservation bias in detection, although it boosts detection capacity. In behavioral experiments we confirmed the prediction, derived from signal detection theory, that this conservative bias in detection is coupled with lowered confidence ratings in a discrimination task. Based on these results, we then used fMRI to test the hypothesis that low pre-stimulus ongoing activity in the dorsal attention network predicts high confidence rating in a visual motion discrimination task. We confirmed this counter-intuitive hypothesis, and also found that functional connectivity (i.e. correlation) between areas within the dorsal attention network negatively predicts confidence rating.

Taken together, these results support the notion that attention may have a negative impact on the decision/criterion aspects of perception. This negative relationship may explain why under the lack of attention, we may have an inflated sense of subjective experience: e.g. the vividness of peripheral vision; and the overconfidence in naïve subjects in inattentive blindness and change blindness experiments despite their poor performance capacity.

Oscillatory and Feedback Activity Mediate Conscious Visual Perception

Tony Ro, City University of New York

Under identical physical stimulus conditions, sometimes visual events are detected whereas at other times these same visual events can go unnoticed. Using both metacontrast masking and transcranial magnetic stimulation (TMS) of the primary visual cortex to induce visual suppression, we have been examining the neural mechanisms underlying this variability in perception. Our results indicate that the timing of arrival of visual events in primary visual cortex with respect to ongoing oscillatory activity and feedback signals play an important role in dictating whether a visual event is detected or not. Furthermore, experiments manipulating visual stimulus saliency suggest that the strength of only feedforward signals, but not feedback signals in primary visual cortex is affected by manipulations of saliency. Taken together, our studies shed some insight into the nature and variability of the neural signals that support conscious visual perception.

S5

Prediction in Visual Processing

Friday, May 6, 2:30 - 4:30 pm, Royal Palm 4-5

Organizers: Jacqueline M. Fulvio, Paul R. Schrater; University of Minnesota

Presenters: Jacqueline M. Fulvio, University of Minnesota; Antonio Torralba, Massachusetts Institute of Technology; Lars Muckli, University

of Glasgow, UK; Eileen Kowler, Rutgers University; Doug Crawford, York University; Robert A. Jacobs, University of Rochester

Symposium Description

In a world constantly in flux, we are faced with uncertainty about the future and must make predictions about what lies ahead. However, research on visual processing is dominated by understanding information processing rather than future prediction – it lives in the present (and sometimes the past) without considering what lies ahead.

Yet prediction is commonplace in natural vision. In walking across a busy street in New York City, for example, successful prediction means both the life or death of the pedestrian and the employment status of the cab driver.

In fact, prediction plays an important role in almost all aspects of vision with a dynamic component, including object interception, eye-movement planning, visually-guided reaching, visual search, and rapid decision-making under risk, and is implicit in "top-down" processing in the interpretation of static images (e.g. object recognition, shape from shading, etc.). Prediction entails combining current sensory information with an internal model ("beliefs") of the world to fill informational gaps and derive estimates of the world's future "hidden" state. Naturally, the success of the prediction is limited by the quality of the information and the internal model. This has been demonstrated by a variety of behaviors described above.

The symposium will focus on the importance of analyzing the predictive components of human behavior to understand visual processing in the brain. The prevalence of prediction suggests there may be a commonality in both computational and neural structures supporting it. We believe that many problems in vision can be profitably recast in terms of models of prediction, providing new theoretical insights and potential transfer of knowledge.

Speakers representing a variety of research areas will lead a discussion under the umbrella of prediction that (i) identifies characteristics and limitations of predictive behavior; (ii) re-frames outstanding questions in terms of predictive modeling; & (iii) outlines experimental manipulations of predictive task components for future work. The symposium is expected to spark interest among all areas represented at the conference with the goal of group discovery of a common set of predictive principles used by the brain as the discussion unfolds.

Presentations

Predictive processing through occlusion

Jacqueline M. Fulvio, University of Minnesota; Paul R. Schrater, University of Minnesota

Missing information is a challenge for sensory motor processing. Missing information is ubiquitous - portions of sensory data may be occluded due to conditions like scene clutter and camouflage; or missing at the present time - task demands may require anticipation of future states, such as when we negotiate a busy intersection. Rather than being immobilized by missing information, predictive processing fills in the gaps so we may continue to act in the world. While much of perceptual-motor research implicitly studies predictive processing, a specific set of predictive principles used by the brain has not been adequately formalized. I will draw upon our recent work on visual extrapolation, which requires observers to predict an object's location behind an occluder as well as its reemergence point. Through the results, I will demonstrate that these predictions are derived from model-based forward look ahead – current sensory data is applied to an internal model of the world. I will also show that predictions are subject to performance trade-offs, such that the choice of internal model may be a flexible one that appropriately weights the quality (i.e. uncertainty) of the sensory measurements and the quality (i.e. complexity) of the internal model. Finally, having established the role of internal models in prediction,

I will conclude with a discussion about how prediction may be used as a tool in the experimental context to encourage general model learning, with evidence from our recent work on perceptual learning.

Predicting the future

Antonio Torralba, Massachusetts Institute of Technology; Jenny Yuen, Massachusetts Institute of Technology

In this talk I will make a link with computer vision and recent techniques for addressing the problem of predicting the future. Some of the representations to address this problem in computer vision are reminiscent of current views on scene understanding in humans. When given a single static picture, humans can not only interpret the instantaneous content captured by the image, but also they are able to infer the chain of dynamic events that are likely to happen in the near future. Similarly, when a human observes a short video, it is easy to decide if the event taking place in the video is normal or unexpected, even if the video depicts an unfamiliar place for the viewer. This is in contrast with work in computer vision, where current systems rely on thousands of hours of video recorded at a single place in order to identify what constitutes an unusual event. In this talk I will discuss techniques for predicting the future based on a large collection of stored memories. We show how, relying on large collections of videos, using global image features, such as the ones used to model fast scene recognition, we can index events stored in memory similar to the query, and how we can build a simple model of the distribution of expected motions. Consequently, the model can make predictions of what is likely to happen in the future, as well as evaluate how unusual is a particular event.

Predictive coding – contextual processing in primary visual cortex V1

Lars Muckli, University of Glasgow, UK; Petra Vetter, University of Glasgow, UK; Fraser Smith, University of Glasgow, UK

Primary visual cortex (V1) is often characterized by the receptive field properties of its feed-forward input. Direct thalamo-fugal input to any V1 cell however, is less than 5 % (Douglas and Martin 2007), and much of V1 response variance remains unexplained. We propose that one of the core functions of cortical processing is to predict upcoming events based on contextual processing. To gain a better understanding of contextual processing in the cortex we focused our fMRI studies on non-stimulated retinotopic regions of early visual cortex (2). We investigated activation along the non-stimulated long-range apparent motion path (1), occluded a visual quarter-field of a natural visual scene (3), or blindfolded our subjects and presented environmental sounds (4). We were able to demonstrate predictive activity along the illusory apparent motion path (1), use decoding to classify natural scenes from non-stimulated regions in V1 (3), and to decode environmental sounds from V2 and V3, but not from V1 (4). Is this contextual processing useful to predict upcoming visual events? To investigate predictability we used our contextual stimuli (apparent motion) as the prime stimuli and tested with a probe stimulus along the apparent motion path to find that predicted stimuli are processed more efficiently – leading to less fMRI signal and better detectability (1). In summary, we have found brain imaging evidence that is consistent with the hypothesis of predictive coding in early visual areas.

Prediction in oculomotor control

Eileen Kowler, Rutgers University; Cordelia Aitkin, Rutgers University; Elio Santos, Rutgers University; John Wilder, Rutgers University

Eye movements are crucial for vision. Saccadic eye movements bring the line of sight to selected objects, and smooth pursuit maintains the line of sight on moving objects. A major potential obstacle to achieving accurate and precise saccadic or pursuit performance is the inevitable sensorimotor delay that accompanies the processing of the position or motion of visual signals. To overcome the deleterious effects of such delays, eye movements display a remarkable capacity to respond on the basis of predicted sensory signals. Behavioral and neurophysiological studies over the past several years have addressed the mechanisms responsible for predictive eye movements. This talk will review key developments, focusing on anticipatory smooth eye movements (smooth eye movements in the direction of the expected future motion of a target). Anticipatory smooth eye movements (a) can be triggered by high-level, symbolic cues that signal the future path of a target, and (b) are generated by neural pathways distinct from those responsible for maintained smooth pursuit. When the predictability of the

target motion decreases, anticipatory smooth eye movements are not suppressed, but rather reflect expectations about the likely future path of the target estimated on the basis of the recent past history of motions. Comparable effects of expectations have been shown to apply to the temporal pattern of saccades. The pervasive influence of prediction on oculomotor control suggests that one of the more important benefits of the ability to generate predictions from either explicit cues or statistical estimates is to ensure accurate and timely oculomotor performance.

Calculation of accurate 3-D reach commands from initial retinal and extra-retinal conditions

Doug Crawford, York University; Gunnar Blohm, Queen's University

Reach movements can be guided in 'closed loop' fashion, using visual feedback, but in biological systems such feedback is relatively slow. Thus rapid movements require 'open loop' transformations based on initial retinal and extra-retinal conditions. This is complicated, because the retina is attached to the interior surface of a sphere (the eye) that rotates three-dimensionally with respect to the world, the other eye, and effectors such as the reach system. Further, head movement causes the eyes to translate with respect to both the visual world and the shoulder. Optimism continues to abound that linear approximations will capture the main properties of this system (i.e., most visuomotor studies implicitly treat the retina as a flat, shifting plane), but unfortunately this ignores several fundamentals that the real brain must deal with. Amongst these is the need for eye and head orientation signals to solve the spatial relationships between patterns of stimulation on the two retinas (for depth vision) and between the external world and motor effectors. Here we will describe recent efforts to 1) understand the geometric problems that the brain encounters in planning reach, 2) determine if the brain actually solves these problems, and 3) model how the brain might solve these problems.

Are People Successful at Learning Sequences of Actions on a Perceptual Matching Task?

Robert A. Jacobs, University of Rochester; Reiko Yakushijin, Aoyama Gakuin University

Human subjects were trained to perform a perceptual matching task requiring them to manipulate comparison objects until they matched target objects using the fewest manipulations possible. Efficient performance of this task requires an understanding of the hidden or latent causal structure governing the relationships between actions and perceptual outcomes. We use two benchmarks to evaluate the quality of subjects' learning. One benchmark is based on optimal performance as calculated by a dynamic programming procedure. The other is based on an adaptive computational agent that uses a reinforcement learning method known as Q-learning to learn to perform the task. Our analyses suggest that subjects were indeed successful learners. In particular, they learned to perform the perceptual matching task in a near-optimal manner (i.e., using a small number of manipulations) at the end of training. Subjects were able to achieve near-optimal performance because they learned, at least partially, the causal structure underlying the task. In addition, subjects' performances were broadly consistent with those of model-based reinforcement learning agents that built and used internal models of how their actions influenced the external environment. On the basis of these results, we hypothesize that people will achieve near-optimal performances on tasks requiring sequences of actions -- especially sensorimotor tasks with underlying latent causal structures -- when they can detect the effect of their actions on the environment, and when they can represent and reason about these effects using an internal mental model.

S6

Integrating local motion information

Friday, May 6, 2:30 - 4:30 pm, Royal Palm 6-8

Organizer: Dujie Tadin, University of Rochester, Center for Visual Science

Presenters: Xin Huang, Department of Physiology, University of Wisconsin; Dujie Tadin, University of Rochester, Center for Visual Science; David R. Badcock, School of Psychology, The University of Western Australia; Christopher C Pack, Montreal Neurological Institute, McGill University; Shin'ya Nishida, NTT Communication Science Laboratories; Alan Johnston, Cognitive, Perceptual and Brain Sciences, University College London

Symposium Description

Since Adelson and Movshon's seminal 1982 paper on the phenomenal coherence of moving patterns, a large literature has accumulated on how the visual system integrates local motion estimates to represent true object motion. Although this research topic can be traced back to the early 20th century, a number of key questions remain unanswered. Specifically, we still have an incomplete understanding of how ambiguous and unambiguous motions are integrated and how local motion estimates are grouped and segmented to represent global object motions. A key problem for motion perception involves establishing the appropriate balance between integration and segmentation of local motions. Local ambiguities require motion integration, while perception of moving objects requires motion segregation. These questions form the core theme for this workshop that includes both psychophysical (Tadin, Nishida, Badcock and Johnston) and neurophysiological research (Pack and Huang).

Presentations by Huang and Tadin will show that the center-surround mechanisms play an important role in adaptively adjusting the balance between integration and segmentation. Huang reached this conclusion by studying area MT and the effects of unambiguous motion presented to the receptive field surround on the neural response to an ambiguous motion in the receptive field. Tadin reports that the degree of center-surround suppression increases with stimulus visibility, promoting motion segregation at high-contrast and spatial summation at low-contrast. More recently, Tadin investigated the neural correlates of centre-surround interactions and their role in figure-ground segregation.

Understanding how we perceive natural motion stimuli requires an understanding of how the brain solves the aperture problem. Badcock showed that spatial vision plays an important role in solving this motion processing problem. Specifically, he showed that oriented motion streaks and textural cues play a role in early motion processing. Pack approached this question by recoding single-cell responses at various stages along the dorsal pathway. Results with plaid stimuli show a tendency for increased motion integration that does not necessarily correlate with the perception of the stimulus. Data from local field potentials recorded simultaneously suggest that the visual system solves the aperture problem multiple times at different hierarchical stages, rather than serially.

Finally, Nishida and Johnston will report new insights into integration of local motion estimates over space. Nishida developed a global Gabor array stimulus, which appears to cohere when the local speeds and orientation of the Gabor are consistent with a single global translation. He found that the visual system adopts different strategies for spatial pooling over ambiguous (Gabor) and unambiguous (plaid) array elements. Johnston investigated new strategies for combining local estimates, including the harmonic vector average, and have demonstrated coherence in expanding a rotating motion Gabor arrays displays – implying only a few local interactions may be all that is required to solve the aperture problem in complex arrays.

The symposium will be of interest to faculty and students working on motion, who will benefit from an integrated survey of new approaches to the current central question in motion processing, and a general audience interested in linking local and global processing in perceptual organization.

Presentations

Stimulus-dependent integration of motion signals via surround modulation

Xin Huang, Department of Physiology, University of Wisconsin; Thomas D. Albright, Vision Center Laboratory, Salk Institute for Biological Studies; Gene R. Stoner, Vision Center Laboratory, Salk Institute for Biological

Studies

The perception of visual motion plays a pivotal role in interpreting the world around us. To interpret visual scenes, local motion features need to be selectively integrated and segmented into distinct objects. Integration helps to overcome motion ambiguity in the visual image by spatial pooling, whereas segmentation identifies differences between adjacent moving objects. In this talk we will summarize our recent findings regarding how motion integration and segmentation may be achieved via "surround modulation" in visual cortex and will discuss the remaining challenges. Neuronal responses to stimuli within the classical receptive field (CRF) of neurons in area MT (V5) can be modulated by stimuli in the CRF surround. Previous investigations have reported that the directional tuning of surround modulation in area MT is mainly antagonistic and hence consistent with segmentation. We have found that surround modulation in area MT can be either antagonistic or integrative depending upon the visual stimulus. Furthermore, we have found that the direction tuning of the surround modulation is related to the response magnitude: stimuli eliciting the largest responses yield the strongest antagonism and those eliciting the smallest responses yield the strongest integration. We speculate that input strength is, in turn, linked with the ambiguity of the motion present within the CRF - unambiguously moving features usually evoke stronger neuronal response than do ambiguously moving features. Our modeling study suggests that changes in MT surround modulation result from shifts in the balance between directionally tuned excitation and inhibition mediated by changes in input strength.

Center-surround interactions in visual motion perception

Duje Tadin, University of Rochester, Center for Visual Science

Visual processing faces two conflicting demands: integration and segmentation (Braddick, 1993). In motion, spatial integration is required by the noisy inputs and local velocity ambiguities. Local velocity differences, however, provide key segregation information. We demonstrated that the balance between integrating and differentiating processes is not fixed, but depends on visual conditions: At low-contrast, direction discriminations improve with increasing size – a result indicating spatial summation of motion signals. At high-contrast, however, motion discriminations worsen as the stimulus size increases – a result we describe as spatial suppression (Tadin et al., 2003). This adaptive integration of motion signals over space might be vision's way of dealing with the contrasting requirements of integration and segmentation, where suppressive mechanisms operate only when the sensory input is sufficiently strong to guarantee visibility. In subsequent studies, we have replicated and expanded these results using a range of methods, including TMS, temporal reverse correlation, reaction times, motion-aftereffect, binocular rivalry and modeling. Based on the converging evidence, we show that these psychophysical results could be linked to suppressive center-surround receptive fields, such as those in area MT.

What are functional roles of spatial suppression? Special population studies revealed that spatial suppression is weaker in elderly and schizophrenic patients – a result responsible for their paradoxically better-than-normal performance in some conditions. Moreover, these subjects also exhibit deficits in figure-ground segregation, suggesting a possible functional connection. In a recent study, we directly addressed this possibility and report experimental evidence for a functional link between surround suppression and motion segregation.

The role of form cues in motion processing

David R. Badcock, School of Psychology, The University of Western Australia; Edwin Dickinson, University of Western Australia; Allison McKendrick, University of Melbourne; Anna Ma-Wyatt, University of Adelaide; Simon Cropper, University of Melbourne

The visual system initially collects spatially localised estimates of motion and then needs to interpret these local estimates to generate 2D object motion and self-motion descriptions. Commonly sinusoidal gratings have been employed to study the perception of motion and while these stimuli are useful for investigating the properties of spatial- and temporal-frequency tuned detectors they are limited. They remove textural and shape cues that are usually present in natural images, which has led to models of motion processing that ignore those cues. However, the addition of texture and shape information can dramatically alter perceived motion direction.

Recent work has shown that orientation-tuned simple cells are stimulated by moving patterns because of their extended temporal integration. This response (sometimes called motion streaks) allows orientation-tuned detectors to contribute to motion perception by signalling the axis of motion. The orientation cue is influential even if second-order streaks which could not have been produced by image smear are employed. This suggests that any orientation cue may be used to determine local direction estimates: a view that is extended to argue that aperture shape itself may have an impact by providing orientation cues which are incorporated into the direction estimation process. Oriented textural cues will also be shown to distort direction estimates, even though current models suggest they should not. The conclusion is that pattern information has a critical role in early motion processing and should be incorporated more systematically into models of human direction perception.

Pattern motion selectivity in macaque visual cortex

Christopher C Pack, Montreal Neurological Institute, McGill University

The dorsal visual pathway in primates has a hierarchical organization, with neurons in V1 coding local velocities and neurons in the later stages of the extrastriate cortex encoding complex motion patterns. In order to understand the computations that occur along each stage of the hierarchy, we have recorded from single neurons in areas V1, MT, and MST of the alert macaque monkey. Results with standard plaid stimuli show that pattern motion selectivity is, not surprisingly, more common in area MST than in MT or V1. However, similar results were found with plaids that were made perceptually transparent, suggesting that neurons at more advanced stages of the hierarchy tend to integrate motion signals obligatorily, even when the composition of the stimulus is more consistent with the motion of multiple objects. Thus neurons in area MST in particular show a tendency for increased motion integration that does not necessarily correlate with the (presumptive) perception of the stimulus. Data from local field potentials recorded simultaneously show a strong bias toward component selectivity, even in brain regions in which the spiking activity is overwhelmingly pattern selective. This suggests that neurons with greater pattern selectivity are not overrepresented in the outputs of areas like V1 and MT, but rather that the visual system computes pattern motion multiple times at different hierarchical stages. Moreover, our results are consistent with the idea that LFPs can be used to estimate different anatomical contributions to processing at each visual cortical stage.

Intelligent motion integration across multiple stimulus dimensions

Shin'ya Nishida, NTT Communication Science Laboratories; Kaoru Amano, The University of Tokyo; Kazushi Maruya, NTT; Mark Edwards, Australian National University; David R. Badcock, University of Western Australia

In human visual motion processing, image motion is first detected by one-dimensional (1D), spatially local, direction-selective neural sensors. Each sensor is tuned to a given combination of position, orientation, spatial frequency and feature type (e.g., first-order and second-order). To recover the true 2-dimensional (2D) and global direction of moving objects (i.e., to solve the aperture problem), the visual system integrates motion signals across orientation, across space and possibly across the other dimensions. We investigated this multi-dimensional motion integration process, using global motion stimuli comprised of numerous randomly-oriented Gabor (1D) or Plaid (2D) elements (for the purpose of examining integration across space, orientation and spatial frequency), as well as diamond-shape Gabor quartets that underwent rigid global circular translation (for the purpose of examining integration across spatial frequency and signal type). We found that the visual system adaptively switches between two spatial integration strategies – spatial pooling of 1D motion signals and spatial pooling of 2D motion signals – depending on the ambiguity of local motion signals. MEG showed correlated neural activities in hMT+ for both 1D pooling and 2D pooling. Our data also suggest that the visual system can integrate 1D motion signals of different spatial frequencies and different feature types, but only when form conditions (e.g., contour continuity) support grouping of local motions. These findings indicate that motion integration is a complex and smart computation, and presumably this is why we can properly estimate motion flows in a wide variety of natural scenes.

Emergent global motion

Alan Johnston, Cognitive, Perceptual and Brain Sciences, University College, London; Andrew Rider, Cognitive, Perceptual and Brain Sciences, University College, London; Peter Scarfe, Cognitive, Perceptual and Brain Sciences, University College, London

The perception of object motion requires the integration of local estimates of image motion across space. The two general computational strategies that have been offered to explain spatial integration can be classified as hierarchical or lateral interactive. The hierarchical model assumes local motion estimates at a lower point in the hierarchy are integrated by neurons with large receptive fields. These neurons could make use of the fact that due to the aperture problem the 2D distribution of local velocities for a rigid translation falls on a circle through the origin in velocity space. However the challenge for this approach is how to segment and represent the motion of different objects or textures falling within the receptive field, including how to represent object boundaries. Apparent global rotations and dilations can be instantiated in randomly oriented global Gabor arrays suggesting that the aperture problem can be resolved through local interactions. The challenge for this approach is to discover local rules that will allow global organizations to emerge. These rules need to incorporate the status of ambiguous motion signals and unambiguous motion signals to explain how unambiguous 2D motion cues (e.g. at corners) influence the computed global motion field. Here we will describe a simple least squares approach to local integration, demonstrate its effectiveness in dealing with the dual problems of integration and segmentation and consider its limitations.

Eye movements: Cognition and scenes

Friday, May 6, 6:45 - 9:30 pm

Orchid Ballroom, Poster Boards 401 - 422

16.401 An oculomotor trace of cognitive engagement

Yoram Bonne¹(yoram.bonneh@gmail.com), Yael Adini², Moshe Fried³, Amos Arieli⁴; ¹Department of Human Biology, University of Haifa, Israel, ²Vision Research Inst., Kiron, Israel, ³Goldschleger Eye Research Institute, Tel-Aviv University, Sheba Medical Center, Israel, ⁴Department of Neurobiology, Brain Research, Weizmann Institute of Science, Israel

The pattern of fixational eye movements is known to be altered in response to perceptual events, with a stereotypical decrease-increase-baseline modulation of microsaccade rate. This modulation is known to be affected by stimulus saliency and attention. However, the functional role and significance of this pattern as well as the hidden processes it may reflect are largely unknown. Here we explored the effect of task-induced cognitive processes on the pattern of microsaccade rate, while controlling stimulus properties. In the first experiment, observers viewed a sequence of 100 randomly ordered small (2 deg) red and blue circles and triangles briefly flashed at 1Hz repetition rate. The observers silently counted the appearance of different target properties (shape, color) in separate runs. The modulation in the event-related microsaccade rate was analyzed for latency and amplitude. We found a significantly longer latency (prolonged microsaccade inhibition >100 ms, peak around 450ms) for target stimuli as compared to distracters (e.g. for counted circles compared to ignored triangles) and even a longer latency for a conjunction condition (counting blue circles). In comparison, counting all of the items or not counting at all, produced another pattern with a large peak around 200ms, not observed in any of the selection conditions. In a second experiment, observers performed orientation discrimination of a briefly flashed Gabor patch, tilted right or left by 30-deg (easy) or 3-deg (difficult). We found a prolonged latency (>100 ms increase) for the difficult condition. Preliminary results indicate that a similar effect can also be observed in the auditory modality. These results demonstrate an oculomotor trace of task-dependent internal processes in which microsaccades are suppressed or activated according to processing load. Microsaccades thus provide an involuntary window into internal brain processes and can be used to explore these processes in healthy as well as non-communicative individuals.

16.402 The Moving Eye is Easy to Spy: How Motion Improves Gaze Discrimination

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Research indicates that people are remarkably good at discriminating where another person is looking (Gibson & Pick, 1963; Bock, Dicke, & Thier, 2008). Indeed, theories of human social attention are predicated on the idea that humans have developed an especially fine ability to use the eyes of others to make inferences about their attentional state (Kobayashi, & Kohshima, 1997). Although this research demonstrates the importance of eyes to attention, little work has examined the specific mechanisms that underlie gaze discrimination itself. The prevailing view is that the discrimination of gaze direction relies on the use of the ratio of iris to sclera in the visible part of the eye (Gibson & Pick, 1963; Olk, Symons & Kingstone, 2008). This theory is based on research that has used static images of eye direction. In real life, however, a change in eye position involves the motion of the eyes themselves as well as a change in the iris:sclera ratio. We examined the role of eye motion in the discrimination of eye movements. Participants were shown two eye images: eyes looking straight ahead and then eyes looking left or right at 1, 2 or 3 degrees visual angle from fixation. This resulted in the apparent motion of the eyes to the left or right. A 200 ms 'blank screen' preceded or followed these eye motion conditions. In the no-motion condition, the 200ms 'blank' display was inserted between the first and second eye image, eliminating the perception of motion. In all cases participants were required to judge eye direction and to rate how confident they were of their decision. Participants were more accurate and more confident of their

judgements in the eye motion condition. These data suggest that motion information is used by the perceptual system to determine the direction of another individual's gaze.

16.403 Stronger perception of magic without social misdirection

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Visual, multisensory and cognitive illusions in magic performances provide new windows into the psychological and neural principles of perception, attention and cognition. Here we investigate a magic effect consisting of a coin "vanish" (i.e. the perceptual disappearance of a coin). A professional magician (Mac King, headliner, Harrah's Las Vegas) performed the vanish, as follows: a) The magician tosses the coin vertically in his right hand; b) The magician pretends to throw the coin from right to left hand, but surreptitiously holds the coin in his right hand, stopping it from flying; c) The magician's left hand closes as if "catching" the supposedly flying coin; d) The magician opens his left hand to show that the coin has disappeared. Naïve observers perceive the coin flying from right to left hand, and are surprised to find the coin 'magically' gone when the magician opens his left hand. Previous research has shown that magicians can use joint attention cues such as their own gaze direction to strengthen the observers' perception of magic (i.e. in the Vanishing Ball illusion). We wondered if the magician's joint attention might similarly enhance this illusion. To answer this question, we presented naïve observers with videos including real and fake coin tosses. The observers' eye positions were simultaneously measured, and their perceptual responses recorded via button press. The magician's head was occluded in half of the trials to control for joint attention. We found that the illusion was strongest in the presentations where the magician's head was occluded, suggesting that joint attention plays no role in the perception of this effect. Further, the observers' eye movements did not significantly influence their perception of the illusion. We conclude that social misdirection is redundant and possibly detracting to this very robust sleight-of-hand illusion.

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16.404 Where Does Visual Joint Attention Come From: A Dual Head-Mounted Eye Tracking Study in Child-Parent Interaction

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We developed a dual eye tracking paradigm that seek to describe the visual learning environment from a young child's viewpoint and to investigate how young children and their partners jointly coordinate their visual attention in a naturalistic task. Six 18-month-old and six 24-month-old toddlers participated in the study with their parents. They sat around a table and were engaged in a free-play task with multiple objects on a table top. Two head-mounted eye trackers were placed on the child's and the parent's foreheads respectively to record their momentary eye movements and the first-person view video. A motion tracking system was used to record their head movements. Computational techniques were applied to detect visual objects in the two first-person views, and data mining efforts, focusing on analyzing the sensorimotor dynamics from eye movements, the first-person view video and head and hand movements, reveal the following results: 1) Gaze patterns from the child and the parent (e.g. number of fixations, duration of fixations) are dramatically different. In particular, the parent monitors the child's gaze direction frequently by looking at the child's face (22% of time) while the child rarely looks at the parent's face (only 6% of time); 2) The parent uses the child's gaze to follow the child's attention by first checking the child's face and then switching to the object of the child's interest, while the child relies more on the parent's hands and manual actions on objects to infer the parent's attention; 3) Visual objects are larger and more salient from a first-person view in the 24-month-old group than those in the 18-month-old group because the older toddlers employ their bodily movements more efficiently and frequently to bring visual objects of interest closer to their eyes (therefore selecting visual information for internal cognitive processes) than the younger ones do.

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16.405 **Dynamic Attention Shifting in Natural Human-Human Interaction**

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We designed an experiment to examine dynamic attention allocation in real-time human-human interaction. In our study, a participant and a confederate sat across a table with multiple visual objects. Participants were asked to engage and attract the confederate's attention to the target object of his own interest. The confederate was instructed to sometimes follow the participant's bid of attention (thus joint attention) and look away in other moments. In this face-to-face everyday attentional task, moment-by-moment eye movements generated by participants were complex and served several roles for internal cognitive processes from facilitating visually guided manual actions on target objects, to generating mutual gaze with the confederate, and to monitoring and using the confederate's gaze to infer his visual attention. Several dynamic eye movement patterns were discovered based on eye and hand movement data from 40 participants: 1) Participants mainly focused on manipulating objects, and spent more time fixating on the target objects than on the confederate's face. 2) However, at those moments that the confederate switched his attention (either following or not following), most often participants quickly switched their gaze from the target object to the confederate's face. This suggests while participants focused on the target object as a part of eye-head-hand coordination to reach for and manipulate visual objects on the table, they also simultaneously used their peripheral vision to monitor the confederate's reaction to his/her bid of the confederate's attention and respond to the confederate's reactions. 4) The exact timing of this attention switch was at around 700 ms after the onset of the confederate's attention shift. 5) In those cases that participants didn't switch their attention to the confederate's face, they involuntarily moved their gaze toward the face indicated by a decrease of the distance between their gaze location and the center of the face.

16.406 **The effects of goal-oriented task on eye-movements during dynamic natural scene observation**

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Eye-movements can be guided by two separate mechanisms: Bottom-up selection is a stimulus-driven mechanism that operates based on the uniqueness or saliency of visual features in a scene. Top-down selection is a goal-oriented mechanism that operates based on the context of the scene, or observer's intention. Although eye-movements are likely to be optimized to deal with dynamic natural scenes, studies of the influence of either top-down or bottom-up mechanisms on eye-movements have only used natural but static stimuli, or dynamic but artificial stimuli. To address this, the present study manipulated the goal-specificity of the task as a manipulation of top-down processing, and examined the influence on eye-movement behaviour while viewing dynamic natural scenes. In the first phase of the experiment, 40 observers were presented with short clips of a singles tennis match and were asked to rank nine items from the clips (e.g. players, ball, court lines, etc) from most to least attended (i.e. non-specific goal task). In the second phase, half the observers were asked to indicate which of the players won the point (i.e. specific goal task [SG]) in addition to performing the ranking task, while the rest performed the ranking task only (i.e. non-specific goal task [NSG]). Results revealed the significant impact of goal-specificity on the distribution of several eye-movement parameters such as saccadic amplitudes and fixation durations. Most importantly, under the SG task, observers showed shorter saccadic amplitudes and shorter fixation durations, especially for those parameters recorded spatiotemporally around the 'ball events' (i.e. serve, hit, bounce and net); this suggests that the SG task might facilitate finer gaze control. We conclude that top-down selection can override bottom-up selection in the guidance of eye-movements even in the dynamic natural scenes which contain highly salient visual features such as motion.

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16.407 **Watching the world go by: Attentional prioritization of social motion during dynamic scene viewing**

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Where does one attend when viewing dynamic scenes? Research into the factors influencing gaze allocation during free-viewing of dynamic scenes have reported that motion is highly predictive of gaze location (Mital, Smith, Hill, & Henderson, 2010; Cog.Comp.). However, it is currently unknown whether this is due to exogenous control of attention or due to a correlation of motion with higher-order, endogenously prioritized features such as animate objects. In dynamic real-world scenes filmed from a static viewpoint, most motion is caused by animate objects such as people and animals or the objects they carry or are carried by, e.g. vehicles. This social motion may be prioritized by attention due to its intrinsic relevance to human observers.

Across two experiments we show that a) the gaze of multiple viewers is more coordinated when free-viewing dynamic compared to static versions of the same scene, b) the predictive power of gaze by motion is due to a correlation with people, c) prioritization of moving people can be overridden by a viewing task that requires attention to be allocated to the static background (e.g. Identify The Location), and d) following task completion, gaze returns to a default prioritization of people. These results emphasize the strong endogenous control of gaze during dynamic scene viewing and our tendency to adopt a default viewing mode which prioritizes social elements of a dynamic scene.

16.408 **Visuospatial attention shifts during non-visual mental tasks**

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We experimentally validate the hypothesis that seemingly irregular eye movements during mental tasks reflect shifts in spatial attention, in turn employed by executive attention to manage short-term memory through a spatial registry system. We build upon recent findings of neuroimaging (Knops, 2009) and patient studies (Koenigs, 2009) that suggest a crucial role for brain regions with visual-spatial characteristics in abstract mnemonic tasks that require memory manipulation. To validate our hypothesis, we recorded human gaze shifts during two mental tasks: either passively maintaining or sorting sequences of five random digits. We manipulated spatial binding of items to visual locations through different visual presentations of the stimuli; however, subjects were instructed and monitored for performing the tasks in memory and in front of a blank screen. In our first experiment we primed spatial binding of items along horizontal and vertical directions and saw when the task is sorting, the difference in normalized distribution of gaze-shift directions (GSD) along the horizontal direction, for horizontal relative to vertical priming, on average is $+4.41\% \pm 1.51\%$ (mean \pm SE) which is significant (t -test, $n=9$, $p < 0.0192$). However, when the task is passive maintaining the difference in GSDs along the on average is $1.3\% \pm 1.76\%$ (mean \pm SE), n.s. (t -test, $n=9$, $p = 0.9288$). In our second experiment we showed that reversing the order of stimuli for mental sorting, leads to a horizontal symmetry in spatial distribution of gaze shifts amplitudes. We chose two categories of 5 digits, identified by these canonical strings: 41230 and 03214. Exemplars for each category were generated by using different digit values while preserving relative ordering. Subtracting amplitude distributions of gaze-shifts leads to an antisymmetric distribution measured by linear correlation of data point of two sides of distributions ($t(-0.78) = -4.318$, $df=12$, $p < 0.0005$). Our findings establish a functional relationship between presumably amodal mnemonic tasks and visual-spatial systems in human brain and might help explain the notable impact of executive memory tasks on visual processing.

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16.409 **Learning and Decision-Making in a Visual Search Task: Influence of Spatial Statistics on Action Planning and Sensory Processing**

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The rich and noisy array of sensory inputs constantly confronted by the brain, along with its limited sensing abilities, requires humans and animals to actively and efficiently acquire sensory information in a goal-directed

manner. One prime example is active visual processing, in which the high-acuity fovea can only attend a single location at a time. In this work, we examine how humans combine top-down spatial knowledge about target location with bottom-up sensory inputs to optimize performance in an active visual search task. More specifically, we impose spatial regularity in target location and examine whether subjects internalize this information, and, if so, how it influences motor planning and/or sensory processing in the search task. Moreover, we investigate how subjects' search strategy adapts to the target's spatial distribution over different configurations, thus revealing how they integrate and extract the relevant information across trials. In terms of motor planning, we find that subjects sequentially fixate the most likely to least likely locations in their search strategy. In terms of sensory processing, we find that subjects have higher false alarm rate in the more likely target locations, and they also take longer to reject a high-probability location when it does not contain the target and less time to confirm such a location when it does contain the target. In terms of learning and adaptation, subjects show improvement of performance at multiple timescales. In addition, we examine if motor modality affects subjects' performance, and the results show no significant difference between saccadic and manual search conditions. Altogether, our results suggest that subjects can learn an abstract representation of spatial statistics in the environment, and exploit this knowledge to optimize both action planning and sensory processing.

16.410 Examining the influence of scene manipulations and task instruction on scanpaths and inhibition of return

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We report multiple experiments examining how task set influences scan paths and inhibition of return (IOR) during scene viewing when the scene expands during viewing (Experiment 1), changes location during viewing (Experiment 2), or rotates during viewing (Experiment 3). It has been previously established that task instruction influences scanpaths and IOR when viewing static scenes. During visual search, individuals are less likely to refixate previously viewed locations and are slower to look at probes at previously viewed locations relative to novel locations. When the task instruction emphasizes memorization, pleasantness rating, or free-viewing, however, the opposite pattern of results is observed, with individuals faster to return to previously viewed locations, suggesting that the influence of memory on eye movements is task dependent. It has not yet been determined, however, how task set and memory influence scanpaths and IOR in tasks which are more akin to real world scene viewing. We provide evidence that various dynamic scene manipulations interact with task set in a manner that alters the influence of memory and the likelihood of observing IOR, with implications for understanding the spatial reference frame of scene-based IOR

16.411 Selecting the targets for saccadic eye movements during a statistical estimation task

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Active visual tasks require (1) evaluating the content of displays based on information acquired during fixation pauses, and (2) choosing where to aim saccades. How do we apportion time and resources between these two operations (e.g., Hooge & Erkelens, 1999; Araujo et al., 2001)? We studied saccadic eye movements during a statistical estimation task in a display containing both target and distractor elements. Displays were made up of 25 circles (41' diam), 12 targets, 13 distractors. Targets, drawn with thin (4') outlines, contained a tilted line whose orientation was drawn from a distribution with mean 10 or 20 deg to the left or right of vertical (SD=25 deg). Distractor circles had wider outlines (5'-6') and contained vertical line segments. The task was to determine the mean tilt (left or right) of the parent distribution of the target line segments. In the absence of distractors, 4.5-6 target circles/2s trial were fixated, with fixation pause durations of 155-220 ms. With distractors present, fixation durations were about the same, the number of targets fixated/trial decreased, distractors were fixated frequently, and the accuracy of perceptual judgments declined. The ability to avoid distractors (without changing fixation pause duration) was somewhat better when the discriminability of the distractors from the targets increased. In separate "look only" conditions, fewer distractors were

fixated, but only by increasing fixation pause duration up to 300 ms. These results show a reluctance to increase fixation duration for the purpose of improving target selection, even when such strategies would improve task performance. Preferences favor a high rate of saccadic production (Wu et al., Vision Res. 2010). This strategy, which leads to many useless fixations, is costly in terms of time and performance accuracy, but may reduce the overall cognitive load of the task.

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16.412 The temporal dynamics of target and distractor occurrence in the global effect of saccades.

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Background: In the global effect, saccades are displaced in the direction of a distractor near to the target, an effect that may reflect weighted averaging of neural activity in a collicular map. However, the dynamics of the temporal relationship between distractor and target necessary to generate the global effect are not known. Objective: Our goal was to determine the impact of temporal dissociations between the distractor and target on the global effect. Methods: In the first experiment, 12 subjects performed saccades to targets at 8° eccentricity on the horizontal meridian, with and without distractors located at either 4° (near) or 12° (far) eccentricity. Both targets and distractors appeared for 10 ms only. Distractors appeared at 0ms (simultaneous), 20, 30, 40, 50 or 60ms after target onset. In the second experiment, 12 other subjects performed a similar experiment with a wider range of temporal offsets, of 0, 20, 40, 60, 70, 80, 90 and 100ms. The global effect was reflected in the difference in saccade amplitude between conditions with near versus far distractors. These amplitude data were analyzed first as a function of target-distractor offset. Next we assessed them as a function of integration time, meaning the time between distractor onset and saccade onset. Results: Both experiments showed that robust global effect could still be obtained with large target-distractor asynchronies, even up to 100ms. The integration time analysis showed that a global effect could be generated by integration times as low as 90ms, and maximal for integration times of 100-160ms. Conclusions: Simultaneous onset of targets and distractors are not essential for the global effect. Distractors can generate a global effect even if they appear only 90ms before the saccade is made, which is shorter than the 130-140ms 'constant reaction time' found in studies using double-step saccade paradigms.

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16.413 Changes in oculomotor behavior induced by a simulated central scotoma

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The visual system often adopts one or more preferred retinal loci (PRL) for fixation in response to central field loss caused by real or artificial scotoma. White and Bedell (1990) found that one-third of their subjects with central field loss demonstrated complete oculomotor re-referencing, shifting the oculomotor reference from the fovea to a non-foveal PRL. Whether a PRL induced by artificial scotoma can lead to a similar shift of the oculomotor reference remains unclear.

We used a gaze-contingent display to simulate a 10-degree central scotoma. Normally-sighted subjects performed a demanding visual-search task for up to 15 hours (spread over weeks) without being instructed on how to use their peripheral vision. The task contained two components: 1) target-object tracking, requiring subjects to track the search target as it was randomly displaced against a uniform background; 2) visual search, requiring subjects to detect the search target amidst clutter. Oculomotor performance was measured during the object-tracking component.

We observed a fast establishment of PRL (within 3 hours of testing) in all four subjects. Three subjects spontaneously formed a single PRL for fixation near the border of the scotoma, while the fourth developed two PRLs. For the single-PRL subjects, median saccade-latency continued to decrease throughout the experiment (below 300 ms after 7 hours). For these three subjects, their first saccade landing position after each target movement was near their fixational PRL and distant from the fovea, demonstrating

oculomotor re-referencing. The variance of the first-landing site dropped below 0.5 degree within 8 hours. The same PRL was retained for at least one week after the experiment.

Our results suggest that PRL induced by an artificial central-scotoma generally leads oculomotor re-referencing within a relatively short period of time. The artificial scotoma is viable for modeling the oculomotor behavior of patients with central scotoma.

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16.414 Saccade latencies are modulated by previously learned stimulus value

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The execution of a saccade is a very fast and efficient way to direct attention to a stimulus in order to fulfill current goals. The latency and velocity of saccades to visual stimuli are influenced by the low-level properties of the stimulus as well as by its high-level characteristics, e.g., the relevance of the stimulus for a certain task. Here, we asked whether the learned motivational value influences the execution of saccades towards and away from visual stimuli. To this end, we conducted a combined reward-learning and eyetracking study. In the first part of the experiment, participants learned the association between face stimuli and their reward or punishment probabilities. In the second part of the experiment, the same face stimuli were presented in the context of a saccade task. In each trial, one of the faces was presented in the left or right hemifield, along with its scrambled version in the opposite hemifield. Participants were asked to perform a saccade as fast and accurately as possible either to the intact face or to the scrambled face. In this part of the experiment neither reward nor punishment could be obtained. The mean latency of saccades to faces previously associated with a high reward probability was significantly shorter compared to saccades to stimuli with a low reward probability. In contrast, no effect was observed for the previously punished faces. Saccade latencies to scrambled faces were generally longer compared to those towards intact faces, but showed no modulation by the previously learned value. These results demonstrate that short-term learning of motivational stimulus value facilitates fast overt orienting towards visual stimuli, even in a situation where the learned value is no longer task-relevant.

16.415 Dynamic scenes vs. static images: Differences in basic gazing behaviors for natural stimulus sets

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For psychophysical experiments a true natural visual input is mostly not feasible and hence experimental stimuli are simplified, e.g. by employing static images instead of video sequences. Here we present empirical data and modeling results that explicitly compare saccadic eye movement parameters and the resulting gaze-selected regions under dynamic and static stimulus conditions. Data were collected in eye-tracking experiments with 40 natural grayscale videos (duration 5s) and 40 corresponding static stimulus versions. First, we analyzed eye-movement data with respect to various gazing parameters. The most striking effect is a substantial difference in the number of fixations made: Natural videos lead to far less fixations than corresponding static versions (clips 1.89, pics 2.36 fix/s). A close analysis revealed that smooth pursuit eye movements cannot explain this effect and we additionally analyzed first vs. late fixations and total scan path length. We did various controls and also checked with a second set of 21 semi-natural stimuli if the observed differences were due to peculiarities of our data set. This is clearly not the case: Fixation frequency is generally increased, but we find again a marked difference between conditions. An evaluation of the fixated image locations revealed that fixation frequency correlates with luminance variance. To further analyze the dependency on image homogeneity we applied a Gaussian Scale Mixture model to the gaze-selected patches and compared them also to randomly sampled ones. This generative model measures the degree of statistical homogeneity between center and surround locations and we identified conditions for which center and surround are more likely to result from image regions that activate the same set of oriented filters. We finally hypothesize that a

major reason for the observed differences lies in the risk of missing information during a saccade, which obviously only applies to dynamic, but not to static stimulus conditions.

16.416 How does object structure influence saccade targeting within an object?

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How is attention distributed within a spatially extended object? Some evidence suggests that, with multiple seconds of viewing, attention comes to be peaked at the center of an object, even when the end of an object is cued in top-down manners (Alvarez & Scholl, 2005). In addition, eye movements to objects often land at the center of gravity of the object (e.g., Kowler & Blaser, 1995; Melcher & Kowler, 1995), consistent with the idea that covert attention (prior to the saccade) comes to be concentrated at the center of the object. In the latter case, however, center of gravity effects have been observed for goal-directed saccades at relatively long latencies and thus might not reflect the automatic spread of attention through an object. In the present study, we examined the extent to which rapidly generated saccades to a part of an object are biased toward the center of the object. While one end of an extended object was cued, observers attempted to execute a saccade to that region of the object. Part structure was manipulated, with either strong image-based cues to segment the object into parts or no such cues. We predicted that part structure would constrain the spread of attention within the object, reducing the tendency for saccades to be biased toward the center of the object. Surprisingly, in contrast with earlier studies, the landing position of the saccade was not significantly biased toward the object center in either condition. These results indicate that covert attention prior to a saccade can be maintained within one part of an object and does not automatically come to be concentrated in the center.

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16.417 Perceptual and motor IOR: Components or flavours?

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The most common conceptualization of inhibition of return (IOR) is the robust finding of increased response times for saccadic or manual response times to targets that appear at previously cued locations following a cue-target interval exceeding ~ 300 ms in the classic Posner cueing paradigm. Investigative work has explored variants on this cue-target paradigm to determine the extent to which IOR might comprise one or several largely orthogonal components. In a variation on this paradigm, Abrams and Dobkin (1994) presented a directional arrow at fixation as the imperative stimulus for a saccadic response to a placeholder that had previously been cued or uncued. In separate blocks the standard peripheral target was used. The key finding was that the magnitude of IOR was greater when a saccadic response was made to a peripheral than to a central arrow. It was concluded that saccadic responses to peripheral targets comprise motoric and perceptual components (the two components theory for IOR) whereas saccadic responses to a central target comprise a single motoric component. In contrast to the foregoing findings, Taylor and Klein (2000) discovered that IOR was equivalent for central and peripheral targets when these were randomly intermixed suggesting a single, motoric, flavor under these conditions. To resolve the apparent discrepancy, a strict replication of Abrams and Dobkin was conducted central and peripheral targets were either blocked or mixed. In the blocked design, peripheral targets resulted in more IOR than central targets, while in the mixed design, target type had no bearing on the magnitude of IOR. The blocked design creates untoward spatial expectancies for the target that can differentially affect the extent to which non-informative peripheral cues are processed; in other words, the blocked design allows two different attentional control settings, a confound that "masqueraded" as two components of IOR.

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16.418 Spatial Working Memory is Necessary for Embodied Guidance of Insight

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Previous research shows that directed actions can guide people toward insight as they try to solve a difficult problem. Participants led to move their eyes or attention in a pattern that embodies the solution to Dunker's radiation problem are more likely to solve this classic insight problem than participants led to move their eyes in other patterns (Thomas & Lleras, 2007; Thomas & Lleras, 2009). What drives this cross talk between action

and thought? I investigated the hypothesis that spatial working memory is the locus for interactions between action representations and the insight problem conceptualization that they shape. As in previous studies, participants attempted to solve the radiation problem while occasionally performing an unrelated tracking task that guided them either to move their eyes in a pattern related to the problem's solution or to keep fixation in the center of the display. During each tracking period, participants also held either a spatial or verbal stimulus in working memory. Participants who moved their eyes in a pattern that embodied the solution were more likely to solve the radiation problem, but only when the tracking task was paired with a verbal working memory task. Embodied guidance of insight was completely eliminated when participants were instead engaged in a spatial working memory task during tracking. This result suggests that cross talk between action and thought requires spatial working memory resources. It also points to spatial working memory as a potential mechanism driving mind-body interactions.

16.419 Modulation of task-related electrophysiological responses by socially relevant stimuli

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Human faces induce stronger involuntary orienting responses than other visual objects. We recently reported a significant increase in anti-saccade error rates for faces compared to cars and noise patterns, as well as faster pro-saccades compared to the other visual categories (Morand et al., 2010). However, when and where this preferential orienting response is taking place at the neural level remains to be clarified. To address this issue, we investigated the neural dynamics preceding the onset of pro- and anti-saccades elicited by human faces and non-face visual objects normalized for their low-level visual properties (i.e., amplitude spectra and contrast). We simultaneously recorded high-density evoked potentials (ERPs) and eye movements in adult observers as they performed randomly interleaved pro- and anti-saccades to a lateralized target. Pro- and anti-saccades directed to the same visual field significantly modulated the electrophysiological signals within the 100-140ms time-period following target onset. These amplitude modulations were associated with distinct electrical scalp topographies. Faces triggering pro-saccades directed to the left and anti-saccades directed to the right (presented in the LVF) modulated the neurophysiological signals over the temporo-occipital electrodes (PO8 and P9) at 130-140ms, which correspond to the right and left counterparts of the face-sensitive N170 component respectively. These neurophysiological modulations were not accompanied with topographic changes, but with an increase in response amplitude for faces. Our data show distinct electrophysiological signatures for pro- and anti-saccades occurring as early as 100 ms after target onset. We believe these to reflect distinct cortical networks, probably recruiting the FEF and DLPFC in their respective role in saccade programming. Critically, faces, compared to other visual objects impact upon saccade programming at several stages by modulating the magnitude of the cortical networks active prior to both pro- and anti-saccades execution. These observations provide the neural dynamics and mapping of the involuntary orienting responses for faces.

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16.420 Look at the Choices too: An Examination of Looking Behaviours in a Multiple Choice Test

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The current study examines students' ocular behaviours during a multiple choice exam. Specifically, we are interested in how students would approach a multiple choice item visually and whether there is attention bias due to the location of the options. Participants (N = 22) were students enrolled in an Introductory Psychology class who had recently completed the course midterm exam. For this study, students were administered an alternate but comparable version of the midterm exam designed so that visual behaviours could be measured throughout the exam taking. The exam consisted of 52 multiple choice items with four possible options (one target and three distracters). During exam participation, students' ocular behaviors were recorded using a desktop mounted eye tracker system

(EyeLink 1000). Dwell time, run count, and pupil size were measured in five areas of interest on each item: question, option A, B, C & D. On correct trials we found that students dwelled longer on the target than the question and distracters. Also, they tended to look longer at the earlier options (A & B) than the latter options (C & D). In the cases when target location was at B or C, students showed longer dwell time at the distracters located prior to the target than the distracters located following the target. Furthermore, the run count data revealed that these differences in looking time might be a result of the differences in the number of times they went back to the options. In contrast to the previous research on multiple choice exams that suggests the location of the options has little impact on students' performance, the results of this study demonstrated an attention bias towards distracters that were positioned earlier in an item. These findings suggest that scrambling item options could lead to performance differences based solely on location.

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16.421 Investigating Selective Attentional Biases in Nutritional Food Labels Through Eye-Tracking in the Disordered-Eating Population

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BACKGROUND: Recent research has implicated the role of selective attentional biases in a variety of anxiety disorders. Specifically, in individuals engaging in patterns of disordered eating, such biases are believed to be a moderating factor in food choice and/or avoidance. The current study used eye-tracking methodology to examine how selective attentional biases towards specific stimuli on nutritional food labels were moderated by gender, BMI, and presence of specific patterns of disordered eating. METHOD: A total of 60 participants were asked to complete a triad of clinical eating questionnaires (EDI-3, EDQ, and SCOFF), view a series of nutritional food labels, and decide whether such labels were indicative of healthy or unhealthy foods all while eye-movements were recorded to quantify overall viewing times, number of fixations, and total number of saccades. RESULTS: Overall, participants as a whole spent most time viewing and fixating on calorie values, rating lower calorie values as healthy and those high as unhealthy. In terms of gender, male participants spent more time fixating on protein values, rating higher values as healthy, while females spent more time fixating on carbohydrate values, rating lower values as healthy. Participants at a high-risk for anorexia spent significantly more time viewing and fixating on fat values, rating lower values as healthy and higher values as unhealthy, while participants with a high drive for thinness spent most time viewing sugar and calorie values. CONCLUSION: Results from this study suggest that selective attentional biases affect perception to nutritional food labels and that those biases are influenced by both gender and presence of specific patterns of disordered-eating.

Acknowledgement: NSERC

16.422 Saliency, Memory, and Attention Capture in Marketing

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Visual attention is considered to have great value in marketing. The AIDA (Attention - Interest - Desire - Action) advertising model suggests that attention capture is the first and most important step before the desired consumer consumption behavior takes action. Pre-attentive visual processing accounts largely for building up brand preferences in consumer schema: People tend to choose one brand over the other because they feel familiar with it (mere exposure effect), even though they don't consciously remember having seen the brand or its advertisements before. Marketers have been spending a lot of money and time designing, and choosing effective publicity materials for consumer attention capture. An efficient evaluation tool is thus considered necessary. We propose that saliency map (the computational model of vision) can serve as the useful tool to predict people's eye fixation locations in an advertisement, and help marketers to make strategic decisions choosing the most effective ad for publicity through an objective manner. To test saliency map's efficiency, eye movements from fourteen naive subjects were recorded while eighteen images from scenes of shopping environments were showed to them for two seconds followed by a random mask. Subjects were then asked to recall whether subsequently presented image contained items that were presented in the scene. We found no significant correlation between subjects' recall rates and computed saliency of objects from the scenes; however, the computed saliency

has predicted eye locations three standard deviations above chance. The result has supported other marketing studies on pre-attentive visual processing, and further demonstrated the potential of saliency map in marketing.

Object recognition: Neural mechanisms

Friday, May 6, 6:45 - 9:30 pm

Orchid Ballroom, Poster Boards 423 - 440

16.423 Position in space defines the structure of object representations throughout the ventral visual pathway

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In both monkey and human, there is stronger activation for stimuli presented in the contralateral visual field. This bias extends from low-level to high-level regions along the ventral visual pathway and contributes to the position dependence of object recognition. However, the impact of the contralateral bias on the structure of object representations along the ventral visual pathway remains unclear. Here, we used fMRI to localize cortical regions-of-interest (ROIs), selective for faces, bodies, objects and scenes. Next, in an ungrouped event-related experiment, participants were presented with 7 exemplars from each of 7 categories (bodies, cars, chairs, faces, fans, flowers and houses), 7 degrees of visual angle to the left or right of fixation. We then extracted the response to each of the 98 exemplars from each ROI and used multi-voxel pattern analyses to: 1) decode category in particular ROIs and visual fields, and 2) examine the structure of exemplar representations as a function of both visual field and ROI in the two hemispheres. Consistent with prior reports, we found better decoding of category in the contra- than ipsilateral field across all the ROIs. To examine the structure of representations we extracted the pattern of between-exemplar correlations for each combination of visual field and ROI. We then correlated these patterns with each other and found that visual field was the primary determinant of the structure of representations, with high correlations across ROIs within- but not between-fields. Thus, the correlation between regions in the same hemisphere with different selectivity (faces/houses) was greater than the correlation between regions in different hemispheres with the same selectivity. This suggests that high-level visual object representations are common across ROIs, but differ across retinotopic positions. These findings lead to the prediction that agnosias resulting from unilateral lesions should be more severe in the contralateral field.

16.424 The specificity and distribution of the “mind’s eye”: visual imagery and perception

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Our visual perception is usually determined by an interaction between externally driven “bottom-up” sensory information and internally generated “top-down” signals guiding interpretation of the sensory input and reflecting prior knowledge and intent. Mental imagery, which relies entirely on this top-down signal, provides a means to investigate the nature of top-down signals independent of bottom-up perceptual processing. While prior studies have suggested similar neural substrates for imagery and perception, the specificity of imagery representations and their distribution across visual cortical areas remain unclear. Here we used functional magnetic resonance imaging and multi-voxel pattern analysis in an ungrouped event-related design to conduct a detailed comparison of the neural activation patterns to ten individual objects throughout visual cortex during both visual imagery and perception. We found that visual imagery as well as perception activated a precise and fine-grained representation allowing decoding of individual imagined objects throughout ventral visual areas. Further, there was a close correspondence between the imagery and perceptual representations, allowing cross-decoding between them. However, while there was a posterior-anterior gradient of performance with better perceptual decoding in early visual cortex compared with object-selective regions, imagery decoding was similar across ventral visual areas. Moreover, the structure of representations across visual areas were more similar in imagery than perception, suggesting less transformation of visual rep-

resentations between areas during imagery. Finally, the correspondence between imagery and perception was correlated with independent behavioral measures of participants’ vividness of mental imagery. These results suggest that while perception and imagery share similar neural substrates, even at the individual object level, they remain distinct particularly in terms of the distribution and similarity of representations across visual areas.

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16.425 Object ensemble coding is distinct from texture processing in the parahippocampal place area

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Using the fMRI-adaptation paradigm, we have previously demonstrated that the parahippocampal place area (PPA) is insensitive to image changes as long as the same ensemble of objects is perceived across two images (e.g. two different images of the same strawberry pile). We also showed that this object ensemble processing is remarkably similar to the processing of visual texture in the PPA. This raises the question of whether or not the processing of ensembles in the PPA simply reflects the processing of the texture of the individual objects in the ensemble, rather than ensemble features per se. To address this question, we again used the fMRI-adaptation paradigm and in separate trials we showed participants a sequence of two ensemble images that were either identical, shared object ensemble features (i.e. two different images of the same ensemble), or different (i.e. the shape of the individual ensemble objects differed). Importantly, the texture/material of the individual objects in the ensembles was identical in all conditions. Using an independent localizer approach, our results indicate that the PPA shows a lower response in both the ‘identical’ and ‘shared’ conditions (which did not differ), and a higher response in the ‘different’ condition. Thus, the PPA shows adaptation when the same ensemble is repeated and a release from adaptation when two different ensembles are presented despite the repetition of the texture/material of the individual objects in the two ensembles. This indicates that the response to object ensembles in the PPA is not driven solely by the perception of the texture of the individual objects in an ensemble, but instead reflects the perception of the entire object ensemble.

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16.426 A method to infer the retinotopy with landmark-based cortical surface co-registration

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fMRI studies of the visual system often rely on retinotopy to define the low-level visual areas (V1, V2, V3, hV4) and to establish a correspondence between voxels in these areas and points in the visual space. However, retinotopic mapping is impossible for blind subjects, subjects who cannot fixate, or those with severely compromised visual fields. Here, we evaluate a method for inferring the retinotopy from normally-sighted subjects using a landmark-based cortical surface coregistration technique (Pantazis et al., 2010). This technique relies on manually identified sulcal fundi to constrain the coregistration progress.

Sagittal T1-weighted images of 1-mm isotropic spatial resolution were obtained from five normally-sighted individuals and used to derive a surface representation of their cortices. Retinotopies were obtained using standard methods. Seven sulci in or close to the occipital lobe were manually labelled for inter-subject coregistration. For each subject, we generated a “foreign” retinotopy by coregistering the subject against the four other subjects. The eccentricity and polar-angle maps of the four subjects were projected to the target subject and averaged. Based on these averaged foreign maps, the boundaries between visual areas were drawn using the standard approach. This process was repeated for all subjects.

Across the subjects, we found that the mean absolute deviation between the natively and foreignly defined visual-area boundaries was 3.7+/-1.9 mm on a Talairach-normalized cortex. The mean distance between the centers of the foveal confluence was 7.8+/-5.6 mm. Expressed in cortical distance, the native eccentricity was 1.31+/-0.3 times the foreign eccentricity, and this scaling factor was marginally consistent across the cortex ($r=0.74$).

These results suggest that we can reasonably infer retinotopy and identify the low-level visual areas based on the landmark cortical coregistration, when a native retinotopy is unavailable.

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16.427 Different physiological correlates for perceptual decisions and confidence ratings support multi-stage theories

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Both human and animal observers are capable of giving meaningful subjective ratings (e.g., confidence) in perceptual tasks. Recently, neurons have been identified in primate parietal cortex that code for both confidence and accuracy (Kiani & Shadlen, Science 2009). However, current psychophysical models suggest that subjective ratings may depend on a later stage that is dissociable from the decision regarding stimulus identity (Pleskac & Busemeyer, Psych Rev 2010; Maniscalco et al, JVis 2010).

To test for a dissociation, we asked subjects to discriminate between degraded pictures of faces versus houses, and rate their confidence in each trial. We capitalized on the opportunity to directly record electrical activity from the cortex in presurgical epilepsy patients. This method, unlike conventional EEG, allows us to effectively examine activity at high gamma frequencies (>60 Hz), which are known to closely reflect localized neuronal processing in humans.

Like Kiani & Shadlen (2009), we identified activity in the parietal cortex that commonly reflects confidence and accuracy. However, such common activity was found in the prefrontal cortex too. In early sensory regions, we also found a dissociation between confidence and accuracy, with early occipital activity (150-250ms) most crucial for accuracy and later inferotemporal activity (250-400ms) more important for confidence.

We have previously shown that attention can enhance discrimination accuracy but, counter-intuitively, lowers confidence (Rahnev et al, JVis 2009). We capitalized on this effect to further distinguish between mechanisms for confidence and accuracy. Here we examined pre-stimulus neural activity, as this may reflect spontaneous fluctuation of attention. Consistent with our previous findings, we found that trials with higher theta band (4-7Hz) power in the prefrontal cortex were associated with lower confidence, but a trend for higher accuracy.

Taken together, our results suggest that subjective confidence may depend on late stage mechanisms that are distinct from basic perceptual decision making.

16.428 Deriving a neural basis for ventral temporal cortex

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Categorical information represented in the ventral temporal cortex (VT) can be decoded from functional MRI (fMRI) using multivariate pattern analyses (MVPA). Our understanding of the representational space that encodes this information is incomplete. Category-selective regions have been found for faces, bodies, and places, but these regions cannot explain how fine-scale category information beyond those high-level categories is represented in VT. Here, we present a method to derive a model of representational space in VT that is common to subjects and can capture the fine-scale decodable information content in VT. This representational space model we derived for VT enabled us to successfully perform both within-subject and between-subject classification of categorical information and complex movie scenes. To characterize the dimensions of this space, we mapped their cortical topographies, their response profiles for different animate and inanimate categories, and their functional connectivity with the rest of the brain. We further derived the vectors in this space for different contrasts of interest, such as faces versus objects, human faces versus animal faces etc., and mapped their topographies and functional connectivities with rest of the brain. Category-selective regions – the FFA and PPA – emerge as parts of the cortical topographies of respective contrast vectors mapped in this space. Moreover, this model, being a common model for all of our subjects, allows us to compute such functionally-defined ROIs from localizer data in a subset of subjects and then identify the location of the FFA and PPA in other subjects with no localizer data. These results suggest that our rep-

resentational space model captures coarse- and fine-scale category-related information content in VT that is common across brains and preserves the associated cortical topography.

16.429 The visual system adapts to average orientation

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The visual system efficiently represents summary statistical information in multiple domains. For example, we readily extract the average orientation of a set of lines, the global direction of a collection of moving dots, and the average expression of a crowd of faces. In a series of matched behavioral and fMRI experiments, we explored the neural representation of ensemble coding using an adaptation paradigm. Observers viewed sets of gabors which were jittered around a global orientation (e.g., ± 22.5 deg from horizontal). In one experiment, observers adapted to a set of gabors and judged whether a test set was presented to the left or right of fixation. The test set was either identical to the adapting stimulus, or different in one of two ways: (1) each gabor changed orientation and the global orientation changed, or (2) each gabor changed orientation by the same amount while the global orientation remained the same (“ensemble same”). For each of the three conditions, we measured the elevation in contrast threshold after adaptation as a function of eccentricity. As expected, elevation in contrast threshold was greatest when the test stimulus was identical to the adapting stimulus, and least when the test stimulus was different both locally and globally. Critically, the higher the eccentricity, the more closely the ensemble same condition matched the identical condition, suggesting adaptation to the average orientation. In a complementary fMRI experiment, we measured BOLD response to the same three test patterns using an adaptation paradigm. We found adaptation (i.e., reduced signal) in lateral occipital areas when the ensemble was globally the same. Remarkably, observers perceived and adapted to the average even though an exemplar of the average orientation was never present in the set. Taken together, these results suggest the existence of neural mechanisms tuned to the statistical properties of a set.

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16.430 Frequency-tagging object awareness

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The rate of visual information processing in humans has been studied with different techniques. For example, the Steady-State Visual Evoked Potentials (SSVEP) method modulates stimulus luminance at a specific frequency, and reveals a corresponding “frequency tagging” at rates up to 10-20Hz. Such luminance fluctuations, however, directly affect the earliest processing stages, whose influence cascades to the entire visual system. Hence it is impossible with classic SSVEP to distinguish neural correlates of high-level object representations (semantic content) from low-level activities. Here we present a novel technique called Semantic Wavelet-Induced Frequency Tagging (SWIFT) in which advanced image manipulation allows us to isolate object representations using frequency-tagging. By periodically scrambling the image in the wavelets domain we modulate its semantic content (object form), without disturbing local or global low-level attributes. Human observers (N=16) watched sequences containing no real object, or objects that were either easily or difficultly detectable. Each trial consisted in two periods: a naïve period where the subject saw the sequence for the first time (and sometimes did not consciously recognize the embedded object) and a cognizant period where the sequence was presented again after revealing the object identity. When no object was perceived (i.e., either the sequence contained no object or the object was not recognized), the evoked activity was no different from baseline; but whenever observers were aware of the semantic content a tagging response emerged. In a separate experiment (N=24) we compared SWIFT with classic SSVEP at 8 tagging frequencies between 1.5 and 12Hz. While classic SSVEP was insensitive to object-content, SWIFT responded only to sequences containing objects, and at frequencies up to ~4Hz. The SWIFT technique promises to be an elegant EEG method for tracking high-level activity –our first results indicate that the visual system can only form 3 to 4 distinct object representations per second.

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16.431 Organizing visual object knowledge by real-world size in ventral visual cortex

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Across ventral visual cortex, there are multi-voxel patterns that are reliable and informative about different object categories. However, little is known about whether there is a systematic organization underlying these patterns of activity for different visual objects. While there are many possible overarching organizing dimensions for objects, one fundamental dimension of all real-world objects is their physical size. This dimension is intrinsically involved in how we interact with and experience different objects. Here, we examined the possibility that visual object knowledge in the ventral visual cortex is organized by real-world size.

While undergoing whole brain imaging in a 3T fMRI scanner, observers (N=8) were presented with a stream of objects one at a time for 1 second each. The objects systematically swept through the range of real-world size from small to large (or large to small) every 24 seconds. We used phase-encoding analyses traditionally employed for retinotopic mapping to compute the preferred phase of each voxel and construct lag maps across ventral visual cortex. All but one observer showed a systematic size-related organization of activation, with larger objects activating more medial aspects of the ventral visual cortex and smaller objects activating more lateral aspects of the ventral visual cortex. A smooth continuum across the range of object size was seen in half the observers, while a more categorical (big-medial/small-lateral) organization was seen in the remaining participants.

These data suggest that spatially distributed multi-voxel patterns of activity in ventral visual cortex for different object categories may reflect a systematic high-level organization. The real-world size of the object is thus a potential organizing dimension for visual object knowledge and may be used as a proxy for where in ventral visual cortex different objects are processed and represented.

16.432 Object information in the anterior regions of the intraparietal sulcus

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Humans have an amazing ability to quickly and efficiently recognize and interact with visual objects in their environment. The underlying neural processes supporting this ability have been mainly explored in the ventral visual stream. However, the dorsal stream has been proposed to play a critical role in guiding object-directed actions (Goodale and Milner, 1992). This hypothesis is supported by recent neurophysiology and neuroimaging studies that identified object-selective neural responses in the dorsal stream. For example, there is evidence for a striking similarity in the representation of basic object information in the two pathways (Konen and Kastner, 2008) with higher-order areas in lateral occipital/ventral temporal and posterior parietal cortex responding selectively to objects independent of changes in size and viewpoint. Another line of research has identified object-related activity in more anterior regions of the intraparietal sulcus (IPS), especially for images of tools (e.g., Chao and Martin, 2000). Here, we sought to more clearly delineate object information in the anterior portions of the IPS with respect to topographically defined regions of interest using an adaptation paradigm. Subjects viewed blocks of 2D or 3D shapes under adapted (1 object presented 16 times) or non-adapted (16 objects presented 1 time) conditions. Adaptation effects were observed in and around topographically organized area IPS5, which is located in the most anterior aspects of the IPS, for 3D, but not 2D objects and only in the left, but not the right hemisphere. Interestingly, this activity was located posterior to motor-related grasping activity (actual grasping vs. reaching; Culham et al, 2003), suggesting that it is not a motor representation, per se. Together with our previous studies, these results suggest that posterior regions of the IPS act as a perceptual hub for general object information, whereas more anterior regions selectively represent object properties that are critical for guiding action.

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16.433 Robust spatial coding of categorical selectivity in FFA and VWFA

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It has been controversial whether attention alters the categorical selectivity in regions like FFA and VWFA. Using a back propagation algorithm (polyn et al., 2005), we approached this issue by assessing the multi-voxel pattern classification performances for faces, Chinese characters, and textures in FFA and VWFA, respectively, in an active versus a passive task. We especially examined the response pattern consistency between the two tasks by performing a cross-task classification, in which we trained the algorithm with FFA/VWFA responses in one task and tested its classification performance in the other task. This yielded significant above-chance classifications for all types of test stimuli in both FFA and VWFA, suggesting stable response patterns in both regions independent of attention level. Furthermore, the cross-task classification accuracies could be further improved by simply increasing the amplitudes of GLM-fitted signals while keeping the residuals unchanged. This indicates that noise level, rather than the spatial pattern of neural responses, is modulated by attention.

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16.434 The contribution of Fourier phase and amplitude spectra to image categorisation: an EEG study.

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We quantified the relative contribution of Fourier phase and amplitude spectra to the time course of categorical object processing in humans. Although phase is the main contributor to the visibility of local edges, amplitude might carry global image categorical information; additionally, a special type of phase-amplitude interaction seems to exist, which when disturbed, hampers image categorisation [Gaspar & Rousselet, 2009, Vision Research 49(24), 3001-3012]. We addressed this debate by recording ERPs from 8 normal subjects twice. Participants viewed 9 categories of images containing face, house or random phase information with the amplitude spectrum of a face, a house, or the average amplitude of faces and houses (a 3 x 3 design). Single-trial ANOVAs were performed at all time points and electrodes, with bootstrap spatial-temporal clustering multiple comparison correction. The results indicate major phase sensitivity around 170 ms and 250 ms post-stimulus in all eight subjects, reliably across sessions. Weak amplitude sensitivity occurred before 200 ms in three subjects, reliably across sessions. Additionally, in three subjects, phase and amplitude interacted in modulating ERPs around 240-250 ms, and around 330-350 ms. Both amplitude effects and phase x amplitude interactions had different spatial-temporal scalp distributions compared to phase effects. Our evidence supports the idea that phase information is the main contributor to early categorical ERP differences (<200 ms). Although amplitude spectrum alone seems to be insufficient to support image categorisation, it interacts with phase spectrum in later phases of visual processing. To investigate this interaction, we are currently undertaking a follow-up study using images of faces and houses with parametrically manipulated amount of phase and amplitude information (from 0 to 100% in steps of 10%). Subjects will be tested twice to assess reliability. This new design will allow us to describe precisely the time-course of phase and amplitude ERP sensitivity.

16.435 Surface construction from the onset synchronization of border-ownership cells in V1-V2 model.

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Construction of surface is a crucial step in the integration of image fragments towards shape representation and object recognition. Although neural basis for the surface construction is unknown, border-ownership (BO) selective cells that signal the direction of figure (DOF) appear to play a crucial role. Onset synchronization of BO cells (Dong et al, JoV 2008) is a plausible candidate for binding neural signals to represent surface and its shape. Together with the synchronization, the responses of V1 cells at medial axis (MA; Lee et al, Vis Res 1998) that is located at equidistance from nearby contours may play a crucial role in the early stage of surface

representation. If the propagation of spikes from BO cells is biased toward DOF, the spikes provide sufficient signals for the reconstruction of surfaces by means of MA even at the presence of occlusion. We investigated computationally what signals emerge, with regard to the surface representation, in a biophysically detailed model of V1-V2 network that includes V1 cells, BO cells, lateral connections, and bidirectional connections between V1-V2. The model reproduced the onset synchronization of BO cells. We carried out the simulations of the model with a variety of shapes including those of natural objects to examine how the spikes of BO cells at the synchronization propagate in the network. V1 cells located at equidistance from the contours resulted in strong responses, generating the representation of MA. The correlation coefficient between the MA represented by the model responses and that computed from theory was 0.7, and the mean error of shape reconstruction with respect to the original shape was 0.3, indicating good representation of MA. These results suggest a crucial role of the onset synchronization of BO cells for the early representation of surface and its shape by means of MA.

16.436 Statistics of natural object structures and object recognition

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Object recognition has been the focus of computational modeling and neuro-physiological studies in the last 20 years. Despite enormous efforts, an unanswered question is what object features should be encoded and what the statistics of these features are in natural objects. In this study, we explored this fundamental issue and the statistical principles of object representation and recognition. First, we sampled a large number of small patches from several large datasets of natural objects and classified these patches into different classes. Two patches belong to the same class if they can be transformed to each other by an affine transform (displacement, rotation, and scaling) and smooth nonlinear transforms. Second, for each patch class, we performed independent component analysis and modeled it by a product of probability distribution (PD) of affine transformation and PDs of independent components (ICs). Third, we compiled a large set of natural object structures—hierarchically organized spatial concatenations of structured object patches characterized by a small number of dominant ICs. Fourth, we examined the information content of each object structure and selected a set of structures with high information content for each object category. Finally, we developed a hierarchical, structured probabilistic representation for each object that included a PD of the geometry of multiple object parts and a joint PD of a set of object structures. We tested this framework on several large databases of natural objects and faces and found that this framework gave rise to very good recognition performance. These results suggest that the visual brain may instantiate a large set of hierarchically organized structured PDs of natural objects to achieve very high performance on object recognition. The neural mechanisms underlying these statistical principles of object recognition remain to be discovered.

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16.437 Visual integration in the human brain

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We live in a dynamic world, and seeing is a continuous process. New information about objects becomes available through saccades, with motion relative to intervening obstructions, as our eyes focus and adapt, and as environmental conditions change. Yet it is not the case that each instant brings us a fresh vista that must be parsed anew—we have “buffering” mechanisms for storing visual information about what was just seen, so that new information can be added to it and modulate it. We investigated the time window spanned by this putative buffer, as well as where in the brain the cells instantiating it might be located. We recorded intracranial field potentials from tens of subdural grid electrodes implanted in each of fifteen epilepsy patients while they performed a recognition task. A stream of rapidly changing visual noise (10-30Hz) contained embedded within it an image, an image fragment, or two complementary asynchronous image fragments. Images were grayscale renderings of natural objects chosen to elicit varied electrophysiological responses. In each trial, the subject's task was to indicate whether the embedded image(s) matched a test image pre-

sented at the end. Behaviorally, performance was maximal when whole images or complimentary pairs with short asynchronies were shown. As asynchrony increased, performance dropped, and isolated image halves were the most difficult. We were able to discriminate between whole-image presentations and isolated image fragments using the field potential signals recorded at many electrodes in visual cortical areas. Responses to fragment pairs at short (within 100ms) asynchronies resembled responses to whole images; at longer asynchronies, fragments elicited independent responses. These results show that occipito-temporal visual areas of the human brain can combine information presented across a span of at least 100ms when representing the visual world. These observations impose quantitative constraints on computational models of continuous visual perception.

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16.438 How does the visual system create complex shape and motion features?

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The primate visual system is hierarchically organized (Felleman and Van Essen 1991), such that cells in higher visual areas respond to increasingly complex image features (Duffy and Wurtz 1991; Kobatake and Tanaka 1994; Movshon et al 1985). A widespread assumption is that the complexity of the neuronal tuning in higher visual areas results from the combination of simpler features (coded by the pattern of neural activity from afferent cells in lower visual areas). This feature combination scheme is thought to be conjunctive aka AND-like (Baker, Behrmann and Olson 2002; Wang, Tanifuji and Tanaka 1998) – the response to a combination of parts can be supra-linear (super-additive). Also, the locations of the combined features are important – sub-regions within a cell's receptive field can have different orientation preferences (Anzai, Peng & Van Essen 2007). However, this “conjunction of localized features” mental model has rarely been explicitly or thoroughly tested, despite its simplicity. Furthermore, this qualitative mental model can be implemented in a variety of ways, and it is unclear which (if any) specific computational implementation is able to account for the seemingly disparate phenomena in various ventral and dorsal visual areas. In fact, it is unclear if these visual areas even share a common computational mechanism with regard to increasing feature complexity. Here, we review the evidence supporting such a mental model for both the ventral and dorsal streams. In addition, we present a specific computational implementation, taken from a more general model of visual processing (Jhuang et al 2007; Riesenhuber and Poggio 1999; Serre et al 2007), and show that it is able to account for a variety of results in ventral and dorsal visual areas. Overall, we find evidence that a conjunction of localized features may indeed underlie complex shape and motion feature selectivity.

16.439 Recurrent processing during object recognition

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The ventral visual stream has extensive bidirectional connectivity that has been suggested to promote recurrent processing – what function might this serve in the context of high-level visual processes like object recognition? Previous computational modeling work from our lab has demonstrated that the bidirectional architecture of the ventral visual stream supports a highly robust object recognition system. Specifically, our bidirectional model successfully categorized visual objects from 100 different real-world categories, even under high levels of occlusion, with up to twice the accuracy of a comparable feedforward-only model. Here, we expand on this work by experimentally exploring the recurrent processing dynamics that give rise to the visual system's robustness to occlusion during object recognition. Human subjects categorized images of occluded object stimuli that were followed by a mask on some trials. As predicted by our model, we found a significant interaction between the mask (present or absent) and occlusion (low or moderate) such that recognition performance was differentially impaired when a moderately occluded stimulus was masked compared to a relatively unoccluded one. The model provided a close quantitative fit to subjects' data on the identical stimuli and task parameters as used in the experiment. The model indicated that the mask interfered specifically with the extensive recurrent processing required to resolve the ambiguity present in moderately occluded stimuli, whereas low occlusion inputs could be rapidly resolved and thus were relatively unaffected by

the mask. Together, the results of this experiment and the accompanying modeling work provide support for the view that object recognition is a highly dynamic process that depends on the bidirectional architecture of the ventral visual stream.

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16.440 Transcranial magnetic stimulation to lateral occipital cortex disrupts object ensemble processing

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Several neuroimaging studies have reported that object processing selectively activates the lateral occipital area of the brain (LO). Processing in this area is most often studied by presenting a single object to the central visual field. However, the world outside of the laboratory is comprised of multiple objects. Frequently these objects are part of a larger collection or ensemble of objects. For instance, a flower bed or leaves on a tree contain homogeneous repeating and overlapping objects of different sizes and orientations. Recent neuroimaging evidence suggests that such 'object ensembles' show activation in area LO, much like single object displays. Additionally, object ensemble activation was observed in the scene selective parahippocampal place area. We asked whether transcranial magnetic stimulation (TMS) to LO would disrupt object ensemble processing, as has been shown with single object displays, which would suggest that ensembles recruit similar cortical areas to isolated objects. If no disruption is observed, it may suggest that object ensembles are processed more like scenes, and rely more on cortical areas associated with scene processing. Participants categorized gray-scale photographs of objects ensembles as 'natural' or 'man-made' while simultaneously receiving a double pulse of TMS at 10Hz to functionally defined area LO and to the vertex as a control. Preliminary results demonstrate a significant disruption to categorization during the TMS to LO condition compared to the baseline and TMS to vertex conditions. This disruption may reflect an inability to form a statistical summation of the objects within the ensemble required for accurate categorization. Moreover, this finding suggests that area LO quickly processes shape information from more complex stimuli than single objects.

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Visual memory: Objects and features

Friday, May 6, 6:45 - 9:30 pm

Orchid Ballroom, Poster Boards 441- 453

16.441 Task-specific saliency from sparse, hierarchical models of visual cortex compared to eye-tracking data for object detection in natural video sequences.

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HMAX/Neocognitron models of visual cortex use learned hierarchical (sparse) representations to describe visual scenes. These models have reported state-of-the-art accuracy on whole-image labeling tasks using natural still imagery (Serre, et al., PNAS 2007). Generalizations of these models (e.g., Brumby, et al., AIPR 2009) allow localized detection of objects within a scene. Itti and Koch (Nature Reviews Neuroscience, 2001) have proposed non-task specific models of visual attention ("saliency maps"), which have been compared to human and animal data using eye-tracking systems. Chikkerur, et al., (Vision Research, 2010) have reported using eye-tracking to compare visual fixations on objects in detection tasks within still images (finding pedestrians and vehicles in urban scenes), compared to an extension of an HMAX model that adds a model of attention in parietal cortex.

Here, we describe new work comparing human eye-tracking data for object detection in natural video sequences to task-specific saliency maps generated by a sparse, hierarchical model of the ventral pathway of visual cortex called PANN (Petascale Artificial Neural Network), our high-performance implementation of an HMAX/Neocognitron type model. We explore specific object detection tasks including vehicle detection in aerial video from a low-flying aircraft, for which we collect eye-tracking data from several human subjects. We train our model using hand-marked training data on a few frames, and compare our results to eye-tracking data over an indepen-

dent set of test video sequences. We also compare our task-specific saliency maps to non-task specific saliency maps (Itti et al. PAMI 1998; Harel et al. NIPS 2006). We conclude that activity in model IT cortex projects back to a spatial distribution that correlates well to task-specific visual attention recorded by the eye tracker throughout the video sequences.

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16.442 What makes an image memorable?

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When glancing at a magazine, a website, or a book, we are continuously being exposed to photographs. Despite this overflow of visual information, humans are extremely good at remembering thousands of pictures along with some of their visual details. But are all images created equal? Here, we examined if images have intrinsic features that can make them consistently remembered. We ran a Visual Memory Game on Amazon Mechanical Turk. Participants (n=272) viewed a sequence of images and indicated whenever they noticed a repeat. We measured image memorability as the probability that an image will be remembered after a single view. We found inter-subject consistency in our game, indicating that the memorability of a photograph is a stable property that is largely shared across different viewers (Spearman's $r=0.53$). Given this consistency, we modeled the contribution of a set of global image descriptors to image memorability, and we trained a predictor based on these descriptors. We additionally annotated our images with object and scene labels, and modeled how each of these labels contributed to image memorability. We found that different image features have consistently different impacts on memorability: low-level image features, e.g. color and contrast, correlate weakly with memorability ($r=0.02-0.18$), while multivariate global descriptors and object contents make more robust predictions ($r=0.33-0.41$). We also examined false memories -- those cases in which a participant thinks he or she remembers a picture but in fact has never seen it -- and modeled which image features tend to give rise to these errors. This work demonstrates that memorability is a stable property of an image, and computational techniques can reveal which image features are driving this consistency.

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16.443 A study of visual short-term memory by 'Concentration': Human, spatial-memory-only and object-file simulation results

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Much of what we know about visual short-term memory (VSTM) derives from change detection studies, in which observers are charged with identifying whether two successive stimulus displays, interleaved by a blank interval, are the same or different. More elaborate techniques require observers to indicate what specific element of the display changed, or where a change occurred. However, since a (typically) binary response is required, guess rate is high, the rate of data accumulation is low, and the richness of data gathered is necessarily limited. Furthermore, unless eye tracking is performed, one cannot be sure that the changed stimulus was foveated, predictably reducing detection rate as stimulus displays become more populous, obfuscating capacity estimation. A procedure akin to the game 'Concentration' is proposed in which observers search mosaics for matching stimuli, wherein only two stimuli are visible at any time. This procedure, unlike change detection, is conducive to modelling and simulation, enabling human performance data to be compared to spatial-memory-only models and slot simulations with specific storage capacities and recency/decay effects. In an example experiment, observers matched pairs of unfamiliar faces. Human performance exceeded that of an idealized spatial-memory-only model, being comparable to a simulated observer with a slot capacity of 1 to 2 items; furthermore, no long-term memory accumulation was found, evidenced by linear performance over time. Interestingly, increasing simulated slot capacity beyond 2-3 items had negligible impact on performance, suggesting that limited human VSTM capacity may underlie an optimally parsimonious neural implementation. The procedure proposed is engaging to participants (an inattentive approach would significantly extend trial duration, a disincentive to indolence). Rich data is produced, facilitating partial-match and time-course analyses, and

enabling comparison to model and simulation results. The information unit in simulated analyses is the object-file, compatible with a dominant model of VSTM incorporating eye movements, trans-saccadic memory.

16.445 Infants' abilities to parse and enumerate orthogonal ensembles

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Adults and infants can represent up to three ensembles in parallel (Halberda et al., 2006; Zosh et al., in revision), storing, for example, the approximate number of red and yellow dots present. Critically, in these studies ensembles were defined by a single feature (e.g., colour); leaving unknown how observers represent ensembles from arrays containing multiple orthogonal features. For example, if presented with an array containing many red items and yellow items, where items could be either circles or crosses, can observers perform two orthogonal parses (colour-defined and shape-defined) to enumerate the ensembles? In Experiment 1 we asked whether 9-month-old infants can parse an array into ensembles using only shape. Infants were habituated to arrays containing a constant number of yellow circles and yellow crosses. At test, we found that infants looked longer at novel arrays in which the number of either ensemble (circles or crosses) had doubled, relative to familiar arrays in which the numerosity of each ensemble remained unchanged. This suggests that infants represented both shape-defined ensembles in memory. In Experiments 2 and 3, we asked how infants represent an array containing orthogonal ensembles. Infants were habituated to arrays containing yellow circles, yellow crosses, red circles, and red crosses. In Experiment 2, one of the colour-defined ensembles (e.g., all of the yellow items) doubled in the novel test array, and we found that infants looked longer at these arrays. In Experiment 3, one of the shape-defined ensembles doubled; infants failed to look longer at these novel arrays. In summary, infants can represent ensembles of items based on either colour or shape. But when both features are present in a single array, infants represented colour-defined but not shape-defined ensembles. Infants appear to enumerate multiple ensembles in parallel, but their ability to track orthogonal ensembles may be limited by feature type.

16.446 Reaction-Time Assessment of Form and Color Processing in Visual Short-Term Memories

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We investigate the processing of two features, form or else color, stored in visual short-term memories (VSTMs) in a feature priming task and a feature comparison task. In both tasks a brief prime is followed by a probe at stimulus onset asynchronies (SOAs) ranging from 63 to 1920 ms. The prime's and probe's features could either be congruent or else incongruent. In the priming task Os simply identified as quickly and accurately as possible the probe's feature by pressing one of two designated response keys. In the comparison task Os determined as quickly and accurately as possible whether or not the prime's and probe's feature differed. Our results showed that the VSTM utilized in the priming task was a fast decaying sensory (iconic) store lasting roughly 500 ms; whereas the VSTM utilized in the comparison task consisted not only of the brief sensory store but also a more durable working memory. Our data also suggest that the color and form features, while processed similarly in sensory store, may be processed differently in visual working memory.

16.447 The relationship between apparent motion and object files

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Object files (OFs) play an important role in theories of mid-level vision. On some influential views, OFs operate and persist only via spatiotemporal continuity. One open question concerns what occurs when direct spatiotemporal continuity is absent: do OFs move in accordance with any motion correspondence ultimately resolved? For example, do OFs accord with apparent motion (AM) correspondences, which lack continuous spatiotemporal stimulation. In Experiment 1, subjects were presented with an AM display consisting of two circles that, across two frames, were seen as moving between two noncontiguous locations. We drove specific correspondences along shorter distances, as is typical in AM. The two objects were primed with two symbols and were then moved in a single step; a third symbol appeared, and could either match the symbol from the closer or the further object. We found a robust object specific preview benefit (OSPB) for

the shorter path, in other words, the path along which AM was perceived. In a second experiment this effect persisted even when motion along the shorter path included an impossible featural transformation (circles turning into squares), an OSPB that again accorded with typical AM. In order to control for the possibility that priming simply bleeds to any nearby object, in Experiment 3, the original two objects never disappeared, but two new objects appeared in the would-be AM locations. No AM was perceived, and no OSPB obtained. In Experiment 4, which was nearly identical to Experiment 3, no OSPB obtained despite unique featural matches between the initial and new objects, seemingly because no AM was perceived. Finally, we found that when four spatially separate items were present throughout, phi-motion produced an OSPB, supplying strong evidence that AM correspondences and OF correspondences are controlled by the same basic rules.

16.448 Mean vs. Range in Statistical Summary Representation

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Statistical summary representation, the ability to accurately encode global statistical properties of a scene (Oliva & Torralba, 2006), occurs due to our limited attention span and memory capacity. Identifying the mean size of a set is more accurate than identifying the size of individual members (Ariely, 2001; Chong & Treisman, 2005). Whether this relative accuracy is reached by distributing attention across the entire set, or by sampling a subset such as the maximum- and minimum-sized elements is still in contention (Myczek & Simons, 2008). Here, we directly evaluated use of the range in set representation by constraining observers to discriminate the true mean from the mid-range ((minimum + maximum)/2). Arrays of 3 or 9 squares were briefly presented (133 ms) and observers were asked to identify either the mean size or a member of the array. First, sizes were sampled from a normal distribution, and the effect of choice type was examined (mean versus member or mid-range versus the correct response). When the mean was pitted against the member, reporting the mean size was better than identifying the sizes of individual elements. When the mean was pitted against the mid-range, accuracies hovered around chance. Moreover, observers were actually below chance performance when identifying the member against the true mean or against the mid-range. These results suggest that the mid-range was used as heuristics for mean size. Second, sizes were sampled from a skewed distribution. For this condition, observers were reliably better than chance at distinguishing both the mean and member of a set from the mid-range, suggesting that observers were sensitive to the relative frequencies of the sizes. Together, these results show we have flexible representations of statistical information from sets, including the skew.

16.449 Central attention is used to maintain feature bindings in visual working memory

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The importance of visuospatial attention in the formation of perceptual feature bindings has been well supported (Treisman & Gelade, 1980); however, the role of attention in the maintenance of feature bindings in visual working memory (VWM) has been the subject of more contention (Johnson, Hollingworth, & Luck, 2008; Wheeler & Treisman, 2002). Furthermore, there is some discrepancy between the role of visuospatial attention (Fougnie & Marois, 2009) and central attention (Allen, Baddeley, & Hitch, 2006) in feature binding maintenance. The current study examined whether central attention is required to maintain feature bindings in VWM by introducing an attentionally demanding verbal secondary task during the interstimulus interval of a change detection task. Shape and binding change detection performance were compared to each other when the attention load was high (verbal long-term memory retrieval), low (respond to a tone), or none (no secondary task). In Experiment 1, all attention conditions (high, low, and no load) were randomly intermixed, requiring participants to maintain complex task instructions during all trial types. Binding performance was lower than shape across all attention load conditions. Remembering the instructions may have resulted in a load sufficient to reduce binding performance in the no-attention load condition. Therefore, in Experiment 2, the no-attention load condition was blocked separately from the high- and low-attention load conditions. In this case, shape and binding performance were equal in the no-attention load condition, while binding performance was significantly lower than shape performance when there was a high attention load (retrieval). This suggests that the attentional requirements of

both long-term verbal memory retrieval and remembering detailed instructions can disrupt feature bindings, and that central attention may be necessary to remember feature bindings under certain conditions.

16.450 Are real-world objects represented as bound units? Independent decay of object details from short-term to long-term memory

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Are all properties of a real-world object stored together in one bound representation, or are different properties stored independently? Object information often appears to be bound in short-term memory, but this could be because multiple properties are concurrently encoded from the same objects. Here we use short-term and long-term memory paradigms to examine the independence of different object properties. If object properties decay independently from short-term to long-term memory, then we can infer that object information is not stored in a single integrated representation.

In Experiment 1, we showed observers 120 real-world objects that were arbitrarily colored and categorically-distinct. Following presentation of the objects, we used a 2AFC to probe either the objects' color or object state (e.g., open vs. closed) after either a short-delay or long-delay. We found that despite being matched in short-delay performance, arbitrary color information decayed much more rapidly than the more meaningful state changes after a long delay (7% for state versus 13% for color, $p < 0.05$).

In Experiment 2, we showed observers a set of categorically-distinct objects that varied in two meaningful dimensions (object exemplar and state) which observers remember equally well on average. This was followed by a 4AFC consisting of two exemplars (one familiar, one novel) each in two states (one familiar, one novel) after either a short-delay or long-delay. After a short delay, observers frequently remember both properties about the same objects, but after a long delay they are more independent (18% decrease in boundedness over time, $p < 0.05$).

These data indicate that observers do not form a single bound object representation in memory: instead, conceptually meaningful object properties persist while arbitrary properties like color are forgotten. Even for different object properties that are forgotten at about the same rate, observers tend to forget these properties independently of each other for individual objects.

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16.451 Shape and color conjunction stimuli are represented as bound objects in visual working memory

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The integrated object view of visual working memory (WM) argues that objects (rather than features) are the building block of visual WM, so that adding an extra feature to an object does not result in any extra cost to WM capacity (Luck & Vogel, 1997). However, the integrated object account has been challenged on the basis of two primary grounds. First, it was argued that this view could not explain how binding of features in visual WM could scale up to maintain much more complex objects (Alvarez & Cavanah, 2004). Second, a number of studies have argued that objects that are composed of features from the same dimension (e.g., two colors) are not bound as one object in WM (Delvenne & Bruyer, 2004; Wheeler & Treisman, 2002). This led some to argue for a "weak" object view of visual WM (Olson & Jiang, 2002). The main problem with accepting the weak object hypothesis is that poor performance for multiple-feature objects could also be attributed to failures at other stages of processing of the change detection task rather than WM storage capacity. In the current study, we used the contralateral delay activity (the CDA) as an electrophysiological marker of WM capacity, to test those alternative hypotheses to the integrated object account. In two experiments we presented complex stimuli and color-color conjunction stimuli, and compared performance in displays that had one object but varying degrees of feature complexity. The results supported the integrated object account by showing that the CDA amplitude corresponded to the number of objects regardless of the number of features within each object, even for complex objects (such as random polygons) or color-color conjunction stimuli.

16.452 Parietal representation of small and large number

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Behavioral and brain evidence suggests our numerical abilities are routed in two primitive cognitive systems: a parallel individuation system for representing distinct individuals simultaneously and a numerical magnitude system for representing the approximate numerical magnitude of a group of objects. In the current study, we investigated the neural mechanisms of these systems by directly contrasting processing of small (1-3 objects) and large numbers (8-24 objects), as these numerical ranges typically engage the two systems differentially. Over short blocks, observers watched a continual stream of novel images containing different numbers of objects. On half the blocks observers were instructed to press a button when the number of objects in successive images repeated (number 1-back) and on the other half of the blocks they did so for the repetition of object shapes (shape 1-back). Crucially, half the blocks were small number blocks and the other half were large number blocks. On the shape 1-back task, where task difficulty was similar for small and large numbers, distinct parietal brain responses were observed to small and large numbers. Specifically, regions of right intraparietal sulcus (IPS) responded more to large numbers whereas medial precentral and, in some subjects, regions of the left inferior IPS responded more to small numbers. On the number 1-back task, behavioral performance was lower for large than for small numbers. Correspondingly, additional IPS activation was observed for large numbers in the number 1-back task, suggesting that some of the activity in these regions in the number task is modulated by non-numerical factors such as task difficulty. These results add to recent findings of distinct behavioral and neural signatures for small and large numbers and suggest distinct parietal brain mechanisms underlie the parallel individuation and approximate number systems.

16.453 Is There a Bias Toward Global Information in Visual Working Memory?

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When briefly presented with global and local information, individuals perceive the global information faster, a phenomenon known as the global precedence effect (Navon, 1977). In this study we investigated whether visual working memory (VWM) is also biased toward global information and if binding features to global and local levels occurs more readily than other types of feature binding (e.g., binding features to a serial position). In this experiment, four Navon figures, in which a larger (global) letter is composed of smaller (local) letters, were presented serially. In a blocked design participants were asked to remember global, local, or both letters of the Navon figures and each figures' serial position. At test, participants were to recall a specific letter presented at a given level and serial position. The results did not indicate a strong bias toward global information. Proportion correct when global information was task relevant was not different from proportion correct when local information was task relevant, and when both were task relevant, local errors were not more frequent than global errors. Furthermore, the results suggest that level binding only occurs more frequently than position binding when attention is directed to the global letters. When participants were asked to attend to both local and global information, level errors (reporting a letter at the correct position but incorrect level) occurred more frequently than position errors (reporting a letter at the correct level but incorrect position). In contrast, when only the global information was task relevant, participants made fewer level errors than position errors, and when only local information was task relevant, level and position errors were equally probable. This study suggests that there is a bias toward global information in VWM only when global information, but not local information, is task relevant.

Attention: Neural mechanisms I

Friday, May 6, 6:45 - 9:30 pm

Vista Ballroom, Poster Boards 501 - 517

16.501 Top-down attention alters background connectivity between retinotopic and category-specific visual areas

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The visual system is confronted with more information than it can handle at any given moment, and thus must prioritize a subset of this input for processing. The brain may implement this selection by regulating how information flows through the visual system. Due to the challenge of studying interactions between brain regions non-invasively, most research in humans has focused on modulation of evoked activation in individual regions in visual cortex. The purpose of the current study is to examine attentional modulation of the interactions among regions using fMRI. Observers completed a feature-based attention task in which they viewed composite face/scene images and attended to either faces or scenes for entire scanning runs. Stimulus-evoked responses and global noise were removed from the data, resulting in a more pure index of connectivity (i.e., background connectivity) under each type of attention. We then identified regions of interest (ROIs) in retinotopic occipital cortex (V1/V2/V3/V3a/V4), and category-specific ventral temporal cortex (fusiform face area, FFA/parahippocampal place area, PPA). We hypothesized that background connectivity between the PPA and retinotopic ROIs would be stronger when observers attended to scenes than to faces, and that the reverse would hold for the FFA. This pattern of results was borne out in the data, with the greatest effects occurring in late ventral occipital areas, especially V4. While both types of attention altered connectivity, effects were more robust and widespread for scene attention and the PPA. By comparing periods of attention against separate resting data, we can further assess the extent to which task differences reflect enhanced and/or suppressed connectivity with the task-relevant vs. -irrelevant category-specific ROIs. Our results suggest that sustained top-down attention can modulate background functional interactions in ventral visual cortex independent of evoked responses, providing preliminary empirical support in humans for theoretical models of cognitive control and goal-directed attention.

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16.502 Differentiating subitizing and counting: a voxel based correlational study

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There is an ongoing debate about whether the contrast between efficient visual enumeration of small number (subitizing) and the relatively inefficient enumeration of larger numbers (counting) is subserved by separable processes. All the neuropsychological evidence for distinct subitization and counting processes to date has emphasised behavioural differences between patients, and there is a paucity of data on the underlying neural correlates of any impairments. The present study provides a first lesion-based analysis of the relations of these different aspects of enumeration. We examined subitization and counting across a case series of brain lesioned patients with chronic deficits, correlating any behavioural deficits with data from whole-brain analyses of high resolution MRI scans. We related the range of behavioural performances on visual enumeration to a continuous measure of neural integrity using an observer independent voxel-based approach, separating out gray and white matter. Severe impairments in subitizing were associated with damage to the early visual areas and white matter in the occipito-parietal region, even with visual field defects accounted for in the modelling, while later visual areas were associated with less severe subitizing impairments. In contrast, impairments in counting efficiency were associated with damage to a larger fronto-parietal network, including the left angular gyrus as well as higher visual areas. The data support the argument for distinctive processes, and neural areas, supporting subitization and counting.

16.503 In the zone or zoning out? Tracking neural and behavioral fluctuations in visual attentional state

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Functional MRI studies typically combine data across a scanning session and treat moment-to-moment fluctuations in subjects' attentional state as noise. However, recent studies suggest that attentional state fluctuations interact with trial-by-trial performance and brain activity. To better characterize the neural mechanisms of intrinsic attentional fluctuations, we developed a novel continuous performance task whose minimal exogenous cues force subjects to rely on internal processes to stay on task. In this gradual onset continuous performance task (GO-CPT), subjects are presented with scenes that gradually transition from one to the next at a constant rate (800ms) over 10 minutes, and are instructed to respond to urban scenes and inhibit responses to mountain scenes (10% of trials). Behavioral results confirm that the GO-CPT taxes subjects' ability to sustain attention, as participants make significantly more errors and exhibit more variable reaction times (RT) over time. Subjects' attentional state also fluctuates moment-to-moment during the task, with periods of high RT variability associated with increased likelihood of errors and low RT variability associated with decreased likelihood. fMRI results demonstrate that, within each run, RT variability fluctuates with default-mode network (DMN) BOLD signal, such that DMN activity is lower during high-variability epochs and higher when participants are "in the zone" during low-variability epochs. Additionally, correctly inhibiting a response to rare targets is associated with activity in right prefrontal and posterior parietal cortices (R PFC/PPC), with lower activity preceding subsequent inhibitory errors. Together, these results indicate that periods of stable, consistent attention are accompanied by increased DMN signal, and that engagement of R PFC/PPC underlies accurate response monitoring. These results call into question the widely held belief that DMN activity is detrimental to attentional performance. Instead, this network may be integrally involved in internally-generated states of control.

16.504 The neural correlates of voluntary visual attention to shape, color, and location

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Visual attention can be directed voluntarily to spatial locations and to different visual features such as shape and color. We used functional magnetic resonance imaging (fMRI) to investigate the neural correlates of endogenous attention to those three visual dimensions: shape, color, and position. Simple figures of different shapes and colors were presented in each of the four visual quadrants. Every two seconds, the stimuli changed their shape and color. The outline of each stimulus was notched, and the notch randomly changed position every two seconds. Observers attended to a specific shape, color, or position in the display as instructed by letters presented at fixation and reported the location of the notch in the attended stimulus. This allowed us to assess the deployment of attention to the correct stimulus. In a control condition, observers ignored the shapes and reported the location of a notch in the fixation square. High accuracy rates for every condition suggest observers attended equally to each visual dimension. Eye-tracking in the scanner confirmed that observers kept good fixation during the experiment. The analysis of fMRI data revealed distinct but overlapping cortical networks engaged in the different experimental conditions compared to the control condition. While there was a core posterior parietal region active in all cases of endogenous attention, attention to colors resulted in strong ventral-occipital activation, attention to positions involved strong posterior-parietal activation, and attention to shapes resulted in strong ventral-occipital and posterior-parietal activation. Our study demonstrates that endogenous attention recruits distinct but overlapping cortical networks depending on the attended visual dimension. The results argue for a modular view of voluntary visual attention.

16.505 **The bias towards a contralateral representation in parietal activity is increased during full-field attentional tracking**

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Activation in parietal regions is contralaterally biased, showing a stronger response when attention is directed to the contralateral visual field than to the ipsilateral visual field. Here we explored how parietal activity changes when attention is divided across the both halves of the visual field simultaneously.

While undergoing whole brain imaging in a 3T fMRI scanner, observers performed an attentional tracking task. Displays consisted of 16 circles, with 4 circles appearing in each quadrant of the visual field. A variable number of targets were cued (turned red for 1 second), and then all items appeared identical and moved while observers attentionally tracked the targets.

On some trials observers tracked a single target that appeared in one of the four quadrants. On other trials, two targets appeared in separate quadrants, diagonally across from each other. We then analyzed the patterns of activation for each of these conditions within parietal regions determined by a separate functional localizer run (tracking > passive viewing). Activation patterns for the 2 target diagonal conditions were well predicted by the average pattern of the component target locations. For example, the pattern of activation for tracking 2 targets in the top-left / bottom-right configuration was predicted by averaging the patterns for tracking 1 target in the top-left and 1 target in the bottom right. Interestingly, the patterns of activity were consistent with a weighted average of the component patterns that was biased towards the pattern for the contralateral target location. This bias appeared to be stronger for the left parietal lobe than for the right parietal lobe.

These results suggest that each parietal lobe can select and track targets in both the left and right visual field. However, under conditions of full-field attention, the bias towards a contralateral representation is increased in parietal regions.

16.506 **Binding and selective attention increase coherence between distant sites in early visual cortex**

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We have proposed that the border ownership selectivity that is observed in many neurons in early visual cortex is the result of specific network connectivity (Craft et. al., J.Neurophysiol. 97:4310-26, 2007). According to our model, border ownership cells (B-cells) have reciprocal connections with grouping cells (G-cells) in another level of cortex. A G-cell integrates inputs from B-cells and modulates their firing rates. When a pair of neurons is activated by edges that are part of one figure (the contours are bound), the neurons receive reentrant inputs from the same G-cell. When the contours are part of separate figures, the inputs come from different G-cells. Thus the model predicts that coherence will increase between pairs with bound edges in their receptive fields. Specifically, because pairs that both prefer the bound configuration are connected to the same G-cell, they should display enhanced coherence with binding compared to other pairs. In the model, attention is inserted at a G-cell and propagates back to the B-cells, modulating their firing rates for further processing. Thus as with binding, the model predicts that coherence will increase with attention, especially for pairs that both prefer the bound configuration. We tested these predictions by recording local field potentials and single-unit spiking activity from two electrodes separated by long distances (3-10mm) in macaque areas V1 and V2. We found that binding increases coherence at around 20Hz, especially for pairs that both prefer the bound configuration. Selective attention also increases coherence in the same range, though the effect is more subtle. As with binding, the increase in coherence with attention is more pronounced for pairs that both prefer the bound configuration. These results support the network connectivity proposed by the model. The coherence difference (although not gamma) may play a role in coding binding and selective attention.

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16.507 **Do spatial attention and long-term memory systems overlap?**

Dorsal and ventral attention network engagement during memory retrieval processes

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Such evidence suggests that a set of fronto-parietal areas is involved in directing top-down attention. Recently, evidence has suggested there is also a ventral attention network recruited by the detection of unexpected or unattended behaviorally relevant stimuli. Interestingly, a similar distinction between a dorsal and ventral network has been recently proposed in the episodic memory field, with the dorsal network recruited during goal directed memory retrieval processes, and the ventral network recruited when relevant memories are automatically retrieved and attention must be oriented toward them. While the dorsal and ventral attention and memory networks are thought to recruit similar brain regions, not much is known about how these systems interact. Here, we investigated whether the attention networks were engaged during memory retrieval processes. We used fMRI to localize the attention networks using a traditional Posner cueing paradigm. The dorsal network was defined from activations related to the cue period, while the ventral network was defined from activations related to invalidly versus validly cued targets. In addition, topographic mapping was used to identify areas within posterior parietal and frontal cortex known to be involved in visual-spatial attention. All regions were defined within individual subjects. Most regions activated by the Posner task carried information about memory retrieval success. As predicted, dorsal attention areas were more activated for words that were remembered with low confidence where more memory search was likely required compared to correctly rejected or recollected words. Ventral attention areas either had the greatest activity for recollected words, or showed a general old/new effect. While these results suggest significant overlap between attention and memory systems, there was also a region within the inferior parietal lobe that was uniquely activated by the memory task.

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16.508 **The effect of microstimulation of LIP during a change blindness task**

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When scanning a scene, our attention can be allocated according to the attentional priority of the objects present in the scene. These priorities are represented by peaks of activity in the lateral intraparietal area (LIP), which we have proposed acts as a priority map. In this study, we are interested in understanding how the brain uses the activity in LIP to allocate covert attention. To examine this, we artificially manipulated activity in the priority map by microstimulating LIP while two animals performed a change blindness task. A trial started when the animal fixated a central white spot for 900 to 1300 ms. Then, 4 oriented bars were flashed for 500 ms at equal eccentricities; one of the bars was at the center of the neurons' receptive field (RF). After a gap of 50-150 ms, the bars reappeared for 1000 ms. In some trials, one of the bars had rotated by 90 deg when it reappeared. The animal had to make a saccade to this bar within 600 ms to be rewarded. In the remaining trials, no bar was rotated and the animal was rewarded for maintaining fixation. The behavioral performance was recorded in terms of the percentage of correct responses. On microstimulation trials, an 80 ms burst of 200 μ A peak-to-peak biphasic pulses at 200 Hz was injected into LIP, 250 ms after the first presentation of the bars was extinguished. Both animals showed a decrease in performance on microstimulation trials when the rotation occurred inside the RF. On the contrary, no effect of microstimulation was found when no bar rotated or when the rotation occurred at the opposite location. These results suggest that the microstimulation of LIP disrupts the priority map at the location being stimulated, but does not effect the allocation of attention at other locations.

Acknowledgement: the National Eye Institute, the McKnight Foundation

16.509 Surprises are mistakes: An EEG source localization study of prediction errors

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The ability to recognize a familiar sequence, use that sequence to predict future events, and then monitor the prediction's accuracy comprise core cognitive skills whose neural underpinnings are poorly understood. To characterize neural responses associated with prediction-violating events, we asked subjects to learn novel visuomotor sequences. In this task, subjects viewed a disk that traversed a quasi-random sequence of five linear motion components, and then tried to reproduce the disk's path from memory.

The fidelity of subjects' imitations improved over four presentations of each sequence. To create unexpected, prediction-violating stimuli, deviant segments were occasionally inserted into a sequence with which the subject had become familiar. A high-density scalp EEG system examined the difference between signals evoked (i) by an expected, predictable motion component, and (ii) by an unexpected component.

A realistic head model localized sources of neural activity generated as subjects viewed the two types of motion components. Although ventral prefrontal areas were active throughout viewing of both expected and unexpected segments, the timing and location of other sources differentiated the two. Cerebellar areas were active only during segments whose directions were expected, beginning approximately 150 ms after the disk began to move. In contrast, during unexpected segments, anterior cingulate cortex showed activation, beginning approximately 300 ms after the disk began to move. The time course of such activation may shed light on processes that integrate sensory input with top-down predictions.

Our results suggest that the mechanisms responsible for monitoring the validity of visual predictions for motions in a sequence are similar to those that detect errors in responses, as demonstrated previously in simpler, discrete motor tasks.

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16.510 An analytic assessment of the effects of dietary iron repletion on perceptual and cognitive performance

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Evidence suggests a potentially causal relationship between systemic (blood and brain) iron status and performance on a range of measures of visual and cognitive performance. Unfortunately, the majority of this evidence involves coarse measures of visual and cognitive functioning, general measures that cannot address changes in the specific components of visual performance that may be affected by changes in iron status. We report an effort that in part tested the potential for increasing the resolution of the analysis of this relationship. Subjects (female tea pluckers, 19-55 years, in West Bengal, India) were randomly assigned to receive either iodized salt (control) or iodized salt fortified with iron (double-fortified salt, DFS). Blood indicators of iron status were measured at baseline (BL) and end line (EL), and included hemoglobin (Hb), serum ferritin (sFt), serum transferrin receptor (sTfR), body iron, and C-Reactive protein (CRP). Perceptual and cognitive functioning were assessed at BL and EL using six measures---visual reaction time, two measures of visual detection, the attentional network task, the composite face task, and a visual recognition memory task---selected for their potential for analyzing the components of perceptual and cognitive performance that might be most affected by changes in iron status. Prevalences of iron deficiency and iron deficiency anemia in the DFS group at EL were significantly lower than at BL and differed from the control group at EL. The DFS group showed significantly increased sFt and body iron, and significantly decreased sTfR at BL relative to EL and as compared to the controls, suggesting the efficacy of the dietary intervention. Almost all of the measures of visual performance were improved at EL for the DFS group, with variations across measures in terms of relative effects, providing a detailed analysis of change and allowing for specific hypotheses with respect to underlying brain mechanisms.

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16.511 Neural responses involved in adaptation-induced blindness

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Neural correlates of visual awareness have been studied using displays such as binocular rivalry and motion-induced blindness, in which the perception of a target is replaced by that of a competing stimulus. Recently Motoyoshi and Hayakawa (2010) reported a novel illusion that adaptation to dynamic stimuli can make a gradually-presented target totally invisible without any competing stimuli (adaptation-induced blindness). Here, we recorded magnetoencephalography (MEG) responses during this illusion to determine the neural correlates of awareness for such a competition-free target. The adapting stimulus was a circular patch of drifting grating presented at the upper-left visual field with an eccentricity of 12.5 deg. The test grating was a static grating presented within a Gaussian temporal window that peaked at 1 s after the adaptor offset with a standard deviation of 250 ms. After the initial 30-s adaptation, the sequence of adapting gratings for 5 s and the test grating for 2 s was repeatedly shown. The test gratings appeared either at the adapted location (adapted condition) or at the non-adapted location (non-adapted condition), or did not appear at all (no image condition). The observers fixated on a small black dot at the center of the screen, and were instructed to judge whether they perceived the test grating or not. The MEG responses to the test grating were recorded using 440 ch whole-head MEG system (PQ2440R: Yokogawa, Japan), and beamformer analysis was conducted. We discovered that while the observers perceived nothing on a uniform background in the adapted condition, the invisible test grating produced a significant decrease in alpha and an increase in gamma response around hMT+. The results are consistent with an additional fMRI experiment showing the hMT+ response evoked by the invisible test, and reveal cortical activities that do not prompt perceptual awareness even without any competing inputs.

16.512 Parietal laterality effects in visual information processing during object individuation and identification

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To explain how our visual system encodes multiple objects simultaneously, based on fMRI results from visual short-term memory (VSTM) studies, the neural object file theory argues that the inferior intra-parietal sulcus (IPS) first individuates objects based on their spatial/temporal properties and then the superior IPS and higher visual areas encode their detailed feature information (Xu & Chun, 2009, TICS). Presently it is unknown whether IPS regions from both hemispheres contribute equally or whether one hemisphere plays a more important role in such visual processing.

By subtracting ipsilateral signals from contralateral ones, previous event-related potential (ERP) studies have reported contralateral delay activities (CDA) that share certain similarity with those reported in fMRI studies. This suggests that some of the parietal activities seen in fMRI studies may have a contralateral bias. Meanwhile, neuropsychological studies on neglect and fMRI studies on visual attention have all reported a more bilateral representation in the right parietal cortex and a more contralateral representation in the left parietal cortex.

Here we asked observers to encode two or four object shapes either unilaterally or bilaterally. Regardless of the encoding load, both the inferior and the superior IPS responded strongly to both ipsilateral and contralateral shape presentations. Nevertheless, both regions also showed a small but significant contralateral bias, with the bias being greater in the inferior than in the superior IPS. This is consistent with inferior IPS' involvement in object individuation which is location-based and superior IPS' involvement in object identification which is more feature-based. Interestingly, we did not find any laterality differences between the two hemispheres.

Taken together, these results suggest that (1) CDA results from previous ERP studies may largely originate from the inferior IPS region, and (2) top-down visual attention induced parietal laterality effects reported previously may be dissociable from those seen during object individuation and identification.

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16.513 Implicit processing of features connects shape, motion, and color brain regions

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Attention plays an important role in object recognition by helping observers select features (e.g., shape, motion, or color) that best identify objects in a cluttered and dynamic environment. At the neural level, attention to specific features leads to increased hemodynamic responses in brain regions that selectively process those features. However, the neural fate of unattended features remains largely unknown. One possibility is that unattended features are implicitly processed. This implicit processing may not lead to increased regional responses, but may instead modulate responses in other feature-selective regions thereby integrating multiple object features. To test this, we adapted a Garner paradigm for functional imaging. Observers (N=12) were shown novel objects that had a unique combination of shape, non-rigid motion, and color. They were instructed to attend to each feature in separate blocks, and to respond only when the attended feature was repeated. For each attended feature, there was a baseline block in which both unattended features were repeated on every trial, and a filter block in which both unattended features changed from trial to trial. We expected that fMRI-adaptation would decrease regional responses to unattended features on baseline blocks but not on filter blocks. Consistent with previous work, a whole-brain analysis showed that attention to shape, motion or color led to increased responses in shape-, motion-, and color-selective regions. Surprisingly, there was no main effect of filter versus baseline blocks despite the large perceptual differences between these two conditions. A psychophysiological interaction analysis, however, revealed that motion- and color-selective regions identified by the whole-brain analysis modulated responses in shape-selective regions more so on filter blocks than on baseline blocks. Taken together, our findings suggest that implicitly processing unattended features functionally connects feature-selective regions. This network underlies successful recognition in a dynamic environment.

16.514 A combined structural MRI and tractography approach in visuospatial neglect

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Patients with right hemisphere lesions and visual neglect fail to orient and respond to left-sided objects. There is general agreement that neglect is a heterogeneous, multi-componential syndrome, but the location and identity of the relevant lesion sites remain debated. Twenty-five right-handed patients with subacute strokes in the right hemisphere performed a paper-and-pencil neglect battery. Their performance (scores on each individual neglect test) was mapped to cortical lesions by using voxel-based lesion-symptom mapping (VLSM) method. The principal white matter (WM) association bundles were reconstructed by using diffusion tensor imaging (DTI) tractography. DTI-derived metrics of WM integrity for each tract (fractional anisotropy, mean diffusivity, as well as radial and parallel diffusivities) were also obtained. Distinct cortical regions including the right angular and supramarginal gyri, as well as the middle frontal gyrus were specifically associated with deficits obtained on specific tests. VLSM and tractography both revealed that damage to the right anterior segment of the arcuate fasciculus, connecting Broca's territory with the inferior parietal lobe, correlated with pathological scores in all the tests used. These results indicate an essential role of the WM damage in neglect and open the way for an interpretation of performance dissociations in neglect on the basis of WM bundles disconnections.

16.515 Response modulation in visual cortex by task, stimulus, and spatial attention

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We previously demonstrated that BOLD responses in area MT+ increase when observers perform a speed discrimination task relative to a color discrimination task, regardless of whether a moving or a static stimulus is attended. This suggests that task-dependent response modulation is independent of the physical properties of an attended stimulus. In the present study, we tested this further by determining whether task-driven modulation persists even in the absence of a stimulus, and whether the effect of spatial attention depends on the task being performed. In an event-related design, participants were cued on each trial to prepare for either a speed or color discrimination task on one side of fixation. Following a brief interval, a high-, low-, or zero-density (blank) field of moving colored dots appeared in each visual quadrant. Subjects reported whether or not the two fields on the cued side differed along the cued feature dimension (speed or color). Consistent with our previous results, performing a speed discrimination task increased responses in MT+ relative to a color discrimination task when a stimulus was present. We also found that performing a color discrimination task increased stimulus-driven responses in V4 relative to a speed discrimination task. However, in the absence of a stimulus these task-driven differences disappeared completely. Additionally, the type of task being performed had no influence on the effects of spatial attention in any regions of interest. These results show that task-driven response modulation is dependent on a stimulus being present within the focus of attention, and that the effects of spatial attention are independent of what task is being performed.

16.516 Subthreshold microstimulation of the superior colliculus induces pupil dilation

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The orienting reflex involves a wide repertoire of behavioral and physiological responses that includes not only a rapid shift of gaze, but also pupil dilation (Sokolov, 1963). The superior colliculus (SC) is a critical structure in the brain network that coordinates orienting behaviors, such as overt movements of eyes and head and covert shifts of attention. We sought to examine the role of the SC in pupil dynamics. First, we monitored pupil diameter in two non-human primate subjects during a variety of visual and oculomotor tasks (i.e., step, gap, and delayed- saccades). Pupil size was negatively correlated with saccadic latency (i.e., greater dilation resulted in shorter saccadic latency), suggesting that the amplitude of pupil dilation may be an effective indicator of attentional/cognitive processing during oculomotor tasks. We then examined whether the SC contributes causally to pupil dilation. We delivered a subthreshold train of microstimulation to the SC [train at 300 Hz for 100ms at current between 10 - 50 μ A], so that saccades were not evoked. We found significant pupil dilation within 150ms of stimulation onset. This suggests that the primate SC plays a causal role in inducing pupil dilation as part of the orienting reflex. The possible neural pathways of induced pupil dilation by the SC stimulation will be discussed. Sokolov, E. N. (1963). Perception and the conditioned reflex. New York: Macmillan.

16.517 Neural activity in V1 creates the saliency map

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Zhaoping proposed (Li, 1999, 2002) that pre-attentive computational mechanisms in the primary visual cortex create a bottom-up saliency map. We performed psychophysical, ERP and fMRI experiments to test her theory. In these experiments, stimulus images have a regular Manhattan grid of 15x29 low-contrast bars, presented in the lower visual field. All bars were identically oriented except for a target region of 2x2 bars with another orientation in either the lower-left or the lower-right quadrant. There were four possible orientation contrasts between the target and the background - 7.5, 15, 30 and 90°. To avoid top-down influences, each stimulus was presented for only 50 ms and was followed by a high-contrast mask, which rendered the whole stimulus invisible to subjects (confirmed by a forced-choice test). In the psychophysical experiment, the Posner cueing paradigm was adopted

to measure the spatial cueing effect of the invisible target on an orientation discrimination task. We found that the cueing effect (the saliency of the invisible target) increased as the orientation contrast increased, but saturated at 30°, which can be predicted by Li Zhaoping's V1 model. In the ERP experiment, we measured the amplitude of C1 to the invisible stimulus with various orientation contrasts. C1 is the earliest visual evoked potential component and is generated in V1. In the fMRI experiment, we measured the BOLD response in V1 to the invisible target with various orientation contrasts. Both the amplitude of C1 and the BOLD response in V1 were proportional to the orientation contrast. More interestingly, they were significantly correlated with the cueing effect across subjects. Thus, the overall results support that, in human subjects, neural activities in V1 could represent the bottom-up saliency map.

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Attention: Inattention and attention blindness

Friday, May 6, 6:45 - 9:30 pm

Vista Ballroom, Poster Boards 518 - 525

16.518 Change Detection: Training and Transfer

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Observers often fail to notice dramatic changes to their environment, and such failures can have real-world consequences (e.g., failing to detect hazards while driving). We examined whether 16-hours of adaptive training on a simple change detection task could improve older adults' ability to detect driving-related changes and to perform other cognitive tasks. Participants saw an initial display of 3 or 5 objects, followed by a mask (80 ms) and then a test display in which one object from the initial display was replaced by a novel object. Participants were asked to identify the changed object. We adjusted the initial display time (i.e. encoding time) individually for each subject to hold performance at 75% accuracy. A control group played online card games for 16 hours. Both groups completed two additional tasks, once before and once after training: (a) a change detection task similar to the trained task but using different stimuli (Luck & Vogel, 1997), and (b) a flicker change detection task using driving scenes (Pringle et al., 2001). Training enhanced change detection performance with the trained objects; following training, subjects required significantly shorter presentation durations (mean improvement = 26 ms at set size 3, 212 ms at set size 5) in order to achieve 75% accuracy. However, training led to no differential improvement, compared to the control group, on either of the untrained tasks. That is, training led to improvements on the trained task but did not generalize to other change detection tasks. Although the ability to detect changes might be trainable, training benefits apparently do not extend beyond the specifically trained task.

16.519 No Gist Perception Without Attention

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In 1998 Mack and Rock described results that have been mistakenly interpreted to mean that the gist of a scene can be perceived in the absence of attention (Koch & Tsuchiya, 2006), and in 2002 Li et al. presented data supporting their claim that gist can be perceived in the near absence of attention. We present results consistent with those reported by Cohen, Alvarez, and Nakayama (2009) that there is no gist perception without attention. In a series of experiments using our inattention procedure (Mack & Rock, 1998), subjects were asked to report the longer arm of a cross briefly presented either at fixation or in the periphery. On critical trials in the inattention, divided, and full attention conditions, the image of a scene (4.7 by 3.6 degrees) was located in the periphery centered 5.9 degrees from fixation when the cross was central or central when the cross was peripheral. It replaced a mosaic pattern present on all previous trials. After reporting the longer cross arm, subjects on these trials were queried about what else they had seen. Six different scenes were used, one of them resembling a picture used by Mack and Rock and several similar to those used by Li et al. (2002). The results were clear. Of the 120 subjects tested, only 22 reported gist in the inattention condition while 90 reported gist with full attention (p

<.000). Our results strongly indicate that gist perception requires attention. Moreover, it is significantly more difficult to perceive gist when the scene is in the periphery (p <.05). Furthermore, in the divided attention condition there was a trade off between accuracy of cross reports and gist perception, again attesting to the need for attention to perceive gist.

16.520 Unconscious pop-out: attentional capture by unseen feature singletons only when top-down attention is available

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In visual "pop-out", a unique visual target (e.g. a feature singleton) can be rapidly detected among a set of homogeneous distractors. However, the role of visual awareness in this process remain unclear. Here we show that, even though subjects were not aware of a suppressed pop-out display, their subsequent performance on an orientation discrimination task was significantly better at the pop-out location than at a control location. These results indicate that visual awareness of a feature singleton is not necessary for it to attract attention. Furthermore, our results show that the subliminal pop-out effect disappeared when subjects diverted their attention toward an RSVP task while viewing the same subliminal pop-out display, suggesting that the availability of top-down attention is necessary for the subliminal pop-out effect.

16.521 Negative Choice in Inattentional Blindness

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We explored whether the phenomenon of Negative Choice (Allakverdiv, 2009), a tendency to be unaware of a stimulus you were previously unaware of, occurs for the critical stimulus not seen due to inattentional blindness (IB) (Mack and Rock, 1998). Using a sustained IB procedure, (Simons & Chabris, 1999), observers watched the ball tossing video and counted the number of passes of balls during which an umbrella-carrying woman, (the critical stimulus), walks through the scene. Following the video, subjects had to identify each of 12 grayscale images of people with accessories (e.g. a man with a suitcase), including an image of the "umbrella-woman" (the IB target). In order to make identification more or less difficult, each of the images was overlaid with a snapshot of the video scene that did not contain the critical stimulus. These overlays created different levels of opacity ranging from 20% to 90%, thus varying the visibility of the target image while preserving the context of the video and making the identification task more or less demanding. 126 observers were tested and nearly 60% demonstrated IB. The dependent measure was the percentage of correct identifications of target images associated with degree of opacity. The results revealed that IB observers were only able to identify the target image to which they had previously been blind when the image was 30% percent more visible than it was to control subjects who had not participated in the IB experiment (p<.01). There was no difference in the level of identification of non-target images between IB subjects, non-IB subjects, and control subjects who did not watch the video. We interpret the data obtained to be a demonstration of Negative Choice of a stimulus previously unseen during a sustained Inattentional Blindness procedure.

16.522 Prior perceptual decisions drive subsequent perceptual experience: Negative priming increases inattentional blindness

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The capacity of visual awareness is limited, with people often failing to see unexpected stimuli that appear in front of their eyes, a phenomenon known as inattentional blindness (IB). People can modulate IB in the moment by prioritizing subsets of the features before them, but to what degree do perceptual decisions at one time impact rates of IB down the line? For example, does a history of ignoring a particular feature lead to decreased noticing of that feature later? To test this, we combined an inattentional blindness paradigm with a negative priming procedure. On 49 trials, a cross appeared for 200-ms before being masked and participants judged the relative lengths of its horizontal and vertical extents. On the final trial, a green or red triangle appeared in one of the cross's quadrants, and participants were probed for their awareness of it. Importantly, interleaved with the first 48 of these trials were "digit task" trials, in which a green and red digit appeared simultaneously, each in what would have been one of the cross's quadrants. Half of the participants were instructed always to identify the green digit and half

always identified the red digit. Thus, the triangle's color on the final trial was the same as either the attended digits (positive priming) or the ignored digits (negative priming). We additionally incorporated a neutral condition, in which only one digit – the opposite color as the triangle – appeared on each “digit task” trial, negating the need to ignore any non-target colors. Results revealed that although IB rates were nearly identical in the neutral and positive priming conditions (20% and 25%, respectively), IB was significantly higher in the negative priming condition (48%). Thus, attentional decisions not only modulate perception in the moment; they also continue to govern the contents of awareness down the line.

16.523 The effects of attentional capture on the target-present and target-absent trials in change blindness

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Change-blindness studies have much been conducted of how changes in target objects are detected or missed, but not so much focused on perceptual processing for non-target objects. A change detection task includes a target-present trial in which a change occurs between two scenes from one view to the next and a target-absent trial in which no change occurs between two consecutive scenes. In this study, we explored what differences might be observed between the target-present and target-absent trials when attention is diverted from a search array by attentional capture. Ten participants detected a change in the search array consisted of a fixation cross with 6, 12, 18 or 24 small bars. In the target-present trials one of the bars changed from red to green or vice versa. In the target-absent trials the same search display was presented once again. The participants' attention was diverted from the search array under the condition of attentional capture, resulting in the reduction of their attention to be directed to the search array. The results show that the target-present trials were more difficult than the target absent trials. Further, the effect of attentional capture was not observed in the target-present trials [$F(1, 27) = 1.849$, ns], whereas in the target-absent trials the effect was observed [$F(1, 27) = 11.832$, $p < .01$]. The lowered percentage correct by attentional capture in the target-absent trial means that the participants perceived “a change” despite the absence of a change object in the search array. This may indicate the possibility that participants detected a coarse change that the two scenes are different before they identified what feature or which object changed where and how it changed. It is possible to assume a mechanism in which perceiving such a coarse change is followed by comparison/verification of detailed representations to confirm where and what change occurred.

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16.524 Temporal processing units relocate the attentional blink.

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When observers are asked to report on two targets (T1 and T2) embedded in a rapid serial visual presentation stream, the identification of T2 is impaired if it appears 180-450 ms after T1 – a phenomenon known as the attentional blink (AB). There is evidence of top-down influence upon the AB. E.g. our previous studies have shown that the AB disappears if T1 and T2 (separate letters) are embedded in a stream of letters forming a word (Falikman, 2002). The follow-up research has demonstrated that the AB disappears if observers are instructed to read a word, even when presented with an incoherent stream of letters (Stepanov, 2009). However, the AB might have shifted to the end of the word, rather than completely disappear. To test this hypothesis, we used cuttable words like “cargo”: in an RSVP stream of successive letters, such a word could be read as either a five-letter word “cargo” or a three-letter word “car”. The RSVP streams consisted of 11 letters, with the first 5 letters forming a cuttable word. The task was to read a word beginning from the 1st letter of the stream and to identify a red letter (T2) which appeared at lags 1-10 after the 1st letter. Half of the 30 subjects were asked to read three-letter words presented for examination before the session, whereas the other half were instructed to read five-letter words. The AB emerged at lag +4 after the 1st letter in the RSVP stream (SOA 440 ms) in the first group of subjects and at lag +5 (SOA 550 ms) in the second group, i.e. after either the word (for three-letters words) or the word identification point (for five-letters words). Therefore, the AB marks the end of a processing unit independent of the number of RSVP items it includes.

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16.525 Implicit semantic perception in object substitution masking

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Decades of research on visual perception has uncovered many phenomena, such as binocular rivalry, backward masking, and the attentional blink, that reflect ‘failures of consciousness’. Although stimuli do not reach awareness in these paradigms, there is evidence that they nevertheless undergo semantic processing. Object substitution masking (OSM), however, appears to be the exception to this rule. In OSM, a temporally-trailing four-dot mask interferes with target perception, even though it has different contours from and does not spatially overlap with the target. Previous research suggests that OSM has an early locus, blocking the extraction of semantic information. Here, we refute this claim, showing implicit semantic perception in OSM using a target-mask priming paradigm. Across two experiments, we manipulated the semantic congruency between target words and the color of the mask, and observers made a speeded identification response to the mask color, followed by a target identification (Experiment 1) or detection judgement (Experiment 2). In Experiment 1, we obtained a strong, systematic effect of the semantic congruency of the target word on response time to the mask (priming), such that responses were faster for compatible compared with incompatible target-mask trials. This was the case both when observers correctly identified the target, and, critically, when they did not. In Experiment 2, we also obtained a priming effect both when the target was correctly detected, and when it was missed. Strikingly, however, a pattern of negative priming was observed (faster responses to compatible trials) when the target was missed, whereas the opposite pattern was found when the target was detected. This result converges with previous findings that unconscious and conscious processing can lead qualitatively different patterns of priming. Most importantly, the significant effect of semantic congruency from masked targets in both experiments reveals that semantic information suppressed via OSM can nevertheless guide behavior.

Acknowledgement: Australian Research Council

Color and light: Lightness and brightness

Friday, May 6, 6:45 - 9:30 pm

Vista Ballroom, Poster Boards 526 - 536

16.526 A low-level multiscale filtering account of stimuli often cited as evidence for higher-level mechanisms in brightness perception

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There is a widespread view that higher-level mechanisms, which help to parse the visual scene into components of reflectance and illumination, are required to explain a variety of brightness illusions, and that low-level spatial filtering explanations are inadequate. This idea arises, in large part, from the erroneous assumption that controlling for local (border) luminance differences rules out low-level spatial filtering explanations. This assumption would be valid if spatial filtering was performed solely by high-frequency “edge-detectors”; however, it is now understood that this is not the case and that filtering occurs at multiple spatial scales (Hess, 2003; Wilson & Wilkinson, 2003). This means that areas remote from the test patches can influence their brightness due to multiscale filtering alone and that holding local luminance constant is an inadequate control. Here we investigate the degree to which low-level multiscale filtering can account for brightness perception in a set of visual illusions often cited as evidence for the necessity of higher-level mechanisms. Although local luminance remains essentially unchanged in these stimuli the larger contexts within which these identical targets are embedded do not. It is thus possible that the observed brightness effects can be accounted for by multiscale filtering mechanisms. Psychophysical brightness and lightness matches were obtained at key locations within the stimuli and were compared with predictions from the ODOG multiscale filtering model (Blakeslee & McCourt, 1999). The ODOG model predicted the brightness effects in the snake illusion (Somers & Adelson, 1997), in simultaneous brightness contrast stimuli with multiple illumination cues (Williams, McCoy, & Purves, 1998), in the paint/shadow illusion (Hillis & Brainard, 2007), and within photographs of natural scenes (Gilchrist, 2006). We conclude that although higher-level mechanisms may

enhance the magnitude of these illusions under some circumstances, multiscale filtering provides a unified and parsimonious explanation of these effects.

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16.527 Brightness-related responses in V1 and V2, a computational model

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Brightness information can be in part encoded in monkey V1 and V2 (Friedman et al., 2003, *Journal of Physiology London*; Roe et al., 2005, *PNAS*; Rossi et al., 1996, *Science*; Rossi and Paradiso, 1999, *Journal of Neuroscience*). Some V1 neurons show responses that track the temporal profile of luminance change of surrounding areas that are several degrees away from the cells' receptive fields, while the luminance of the area that covers the receptive fields stays constant (Rossi et al., 1996, *Science*). The response of such neurons in monkeys seems correlated with the perception of simultaneous contrast in humans. However, V1 neurons do not respond to other stimuli that generate induced brightness in humans, such as the Craik-O'Brien-Cornsweet effect (COCE). Interestingly, some V2 neurons' activities are modulated by temporal variations in COCE luminance profiles (Roe et al., 2005, *PNAS*). Our neural model of functional connections in V1 and V2 simulates reported cell responses to both simultaneous contrast and the COCE. Although the model's recurrent connections within V1 and feedback connections from V2 may handle the "simultaneous contrast" response in V1, they cannot support appropriate modulation of activity in V2 corresponding to the center of a COCE-like stimulus without the additional mechanism inspired by the work of Ts'o and Roe (1999, *Journal of Physiology*) and Ts'o et al. (1986, *Journal of Neuroscience*). Certain model V1 neurons send information from luminance edges to model V2 neurons whose receptive fields do not overlap those of the projecting V1 neurons. This type of connection enables the V2 neurons to modulate their response according to contextual information from edges and surrounding areas, as occurs in brightness induction (e.g., the COCE). The model provides an alternative to diffusion-like filling-in and may shed light on possible mechanisms underlying spatio-temporal properties of brightness-related response in V1 and V2.

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16.528 Gamut Expansion as a Function of Articulation

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Gilchrist (1980) claimed that large effects of depth on lightness require a display with an overall luminance range substantially larger than the 30:1 range from white to black. But in 2009 Radonjic and Gilchrist obtained an equally large lightness effect using a display with a 30:1 range, though with greater articulation in each plane. Their stimulus consisted of two equally illuminated Mondrian patterns (twenty patches in each) meeting at a dihedral angle. One pattern was composed of only light gray patches, between white and middle gray. The other had only dark gray patches, from middle gray to black. Their data showed a dramatic gamut expansion; the range of perceived grays within each Mondrian was much larger than the actual range. To test whether increased articulation would produce an even greater expansion, we created two Mondrians with the same low range but higher articulation - 150 patches within each. The two Mondrians were arranged in the form of a dihedral angle and suspended in midair within a vision tunnel. The left Mondrian contained patches ranging from Munsell 2 to 4.5, while the right Mondrian ranged from 4.5 to 9.5. Fifteen observers viewed the display binocularly and matched 4 target patches in each Mondrian using a Munsell chart. We obtained an even greater perceptual expansion than the earlier study. The mean Munsell matches ranged from 3.1 to 9.0 for the light gray Mondrian, and 3.1 to 9.2 for the dark gray Mondrian. In a second study, 15 observers viewed the Vermeer painting "A View of Delft" on a computer monitor and made Munsell matches to seven surfaces depicted, three in the sunlight and four in the shadow. Although the targets in the shadow varied in lightness from Munsell 3 to 5.5, the mean matches ranged from 3 to 7.0.

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16.529 Simultaneous contrast of brightness and color for flashed stimuli

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Perceived brightness and color are affected by surrounding luminance and color. This simultaneous contrast has been thought to involve a slow process, on the grounds that the effect from a temporally modulated annulus disappears at modulation rates higher than 3-5 Hz. We investigated whether the simultaneous contrast was seen in a briefly flashed stimulus by measuring the brightness of a mean-luminance gray test disk (radius 0.5 deg). On a mean-luminance gray background, an annulus centered at the disk was presented for one frame of a CRT display or for 500 ms, whereas the luminance of the disk remained constant. The luminance of the annulus was varied (0-66 cd/m²). Subjects were asked to adjust the luminance of a comparison disk of the same size (surrounded by luminance noise) to match its brightness with that of the test disk. Not only was a simultaneous contrast effect induced from the flashed annulus, but also it yielded a stronger illusion than the longer-lasting annulus. This enhancement was weakened when a spatial gap was introduced between the disk and annulus. The enhancement of simultaneous contrast was also found in equiluminant colors. The color of the annulus was manipulated in eight directions from the central achromatic point on an equiluminant plane in DKL color space, and subjects were asked to match the hue and saturation of a comparison disk with those of the physically gray test disk embedded within the annulus. In all chromatic directions, the flashed annulus similarly led to a stronger illusion than the longer-lasting annulus, suggesting that the enhancement effect involves an early stage of visual processing, e.g., at LGN. We conclude that the simultaneous contrast is not necessarily mediated by a slow process, and discuss the temporal properties of simultaneous brightness/color contrast in relation to existing models of early visual encoding.

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16.530 A fuzzy-edged region is perceived as differing in reflectance on textured backgrounds

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When distinguishing illumination from reflectance edges, luminance gradient (or fuzziness) of the edge is used as a clue. Generally, a fuzzy edge tends to be perceived as an illumination edge. However, we found that when a fuzzy-edged region was placed on textured backgrounds it tended to appear stained or painted rather than differently illuminated. In our experiment, a dark center region, which simulated a cast shadow in terms of luminance contrast, was placed on spatially uniform or textured backgrounds. The luminance edge between the center and surrounding regions was either fuzzy or sharp. Observers were asked to rate how certainly the dark region was perceived as having lower reflectance or dimly illuminated using a 7-point scale. Results showed that the dark region appeared stained on the textured background, whereas it appeared more like a shadow on the uniform background. It should be noted that the results on the textured background go against the belief that both fuzzy edges and textural continuity over the center and surrounding regions favor illumination-edge interpretation. We tested several different textures such as tatami-mat, small pebbles, grass, and marble patterns, and obtained similar results. However, coarse checkerboard patterns produced the results similar to those on the spatially uniform field. Subsequent experiments revealed that spatial frequency of the checkerboard pattern is a critical factor. The fuzzy-edged dark region was perceived as a shadow on checkerboard patterns of lower and higher spatial frequencies and it appeared more like a stain when the spatial frequency was within a limited range around 2 c/deg. Taken together, these results suggest that spatial interaction between texture and luminance gradient of the edge plays an important role in distinguishing reflectance from illumination edges. This interaction seems to change the way to decompose image luminance into illumination and surface reflectance.

16.531 **Size makes a difference: Estimating lightness and luminance contrast with real light**

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It should be possible to match a crisp luminance edge produced by a spotlight to a reflectance edge. In experiment one 40 observers matched either the luminance contrast or lightness produced by a luminance edge from either a large spotlight or a large gray paper to one of 20 small reflectance edges. In experiment two different observers made the same matches only the spotlight and gray paper edges were equal in size to each of the 20 reflectance edges. In experiment one the spot luminance contrast was 9.5:1 and 3.2:1 for increments and decrements, respectively while for the gray paper it was 8.7:1 and 2.9:1 for increments and decrements, respectively. In experiment one, we found large inter-individual variations with the luminance and lightness matches. Second, observers made the histograms of lightness and luminance matches very close to each other, suggesting that when asked to make a luminance match they actually performed a lightness match. Lastly, the luminance contrast and lightness underestimated the actual luminance contrast produced by the spotlight by 24% for decrements and 35% for increments and for the paper by 37% for decrements and 36% for increments. In experiment two the inter-individual variations were reduced overall, while the histograms of lightness and luminance matches remained very close to each other. The spotlight luminance contrast was 4.6:1 and 3.6:1 for increments and decrements, respectively while for the gray paper it was 8.5:1 and 2.8:1 for increments and decrements, respectively. Importantly, luminance contrast and lightness underestimated the actual luminance contrast produced by the spotlight by 0% for decrements (perfect lightness constancy) and 3% for increments and for the paper by 22% for decrements and 22% for increments. Thus, the size of the target affects lightness and luminance contrast matches which are in agreement with Gilchrist et al.'s (1999) area rule.

16.532 **Dichoptic presentation of the contrast asynchrony suggests a retinal locus for the contrast response**

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The contrast asynchrony is a stimulus configuration that illustrates that the visual system has separable responses to color and color contrast (Shapiro et al, 2004; Shapiro 2008). The basic version of the stimulus consists of two disks whose luminance modulates sinusoidally in time at 1 Hz; one disk is surrounded by a dark ring, and the other disk by a bright ring. The luminance of the disks modulates in phase with each other, and the contrast of the disks relative to their surrounding ring modulates in antiphase. When viewing the contrast asynchrony at 1 Hz, observers perceive the disks to modulate in antiphase relative to each other (consistent with the processing of contrast information), but to get light and dark at the same time (consistent with the processing of luminance information). Here we present the results of experiments in which observers viewed the contrast asynchrony dichoptically. We report that no asynchrony is perceived when one eye is presented with modulating disks, and the other eye is presented with the black and white surround rings, nor is an asynchrony perceived in gradient versions of the contrast asynchrony (like Shapiro et al, 2005). We compare these results to dichoptically presented brightness settings. Consistent with what has been reported elsewhere in the literature, black and white surround rings presented to one eye induce brightness changes in disks presented to the other eye. When we present demonstrations that compare the temporal response of the contrast asynchrony to the temporal response of dichoptic brightness induction, the contrast asynchrony occurs at rates much faster than brightness induction (as expected). The results give further evidence that the contrast response can be separated from brightness induction. The results are consistent with a retinal locus of the contrast asynchrony, whereas aspects of brightness induction may occur cortically.

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16.533 **Binocular Fusion Unmasks Rivalrous Suppression of the Craik-O'Brien-Cornsweet (COC) Illusion**

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A patch of uniform luminance except for a centered, vertical spatial transient ('COC edge') appears different in brightness on the left and right sides of the edge. The locus of the neural mechanism mediating this brightness difference is controversial. CONCLUSION: The results show that the neural locus follows resolution of binocular rivalry. METHODS AND RESULTS: A COC edge was flipped randomly (incremental transient left or right of center) on each trial; the task was to report which side of the patch appeared brighter. (i) Baseline measurements established that the COC illusion was correctly perceived 95-100% of the time for our monocularly presented patch with COC edge. (ii) Adding in the same eye three small moving objects on top of the COC edge, covering 10% of it, did not reduce performance. (iii) The same three moving objects presented in only the contralateral eye suppressed the COC illusion, corroborating Boyaci et al. (Current Biology, 2007) and D'Antona et al. (VSS, 2010). For 2 observers, suppression was complete (0%); for 2 others, performance fell to about 50%. (iv) Critically, with the moving objects presented to both eyes in retinally corresponding positions, performance returned to nearly 100%. Therefore, elimination of binocular rivalry, by introducing corresponding moving objects in the COC eye, eliminated suppression of the COC illusion caused by the contralateral stimuli. Controls excluded alternative explanations: (v) contralateral-eye dominance from the moving objects in only the contralateral eye, by oscillating overall patch luminance (0.7 Hz) in the COC-eye, which gave a continuous time-varying percept of the brightness on both sides of the patch (thus no contralateral dominance); or (vi) COC-eye dominance with the moving objects in both eyes, by adding binocular disparity to the corresponding moving objects in the two eyes, which gave perceived stereo depth (thus neither eye was suppressed).

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16.534 **Lightness constancy in visual artists**

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Research to date has produced widely divergent findings in terms of the degree of lightness constancy shown by individuals, and there are hosts of competing models of lightness processing in the brain. We argue here that visual artists—especially painters of representational works—are a useful cohort for investigations of lightness perception because the task of creating representational paintings would appear to require artists to judge natural scene luminance (what artists call "value") accurately in the face of visual system efforts to normalize perceived intensity. Here we investigate the ability to judge illusory luminance differences in a Craik-O'Brien-Cornsweet stimulus in artists with varying expertise. In a 2AFC staircase design, professional realist painters (N=2) show lower overall PSE (point of subjective equality) with respect to real luminance differences, compared to student artists (N=3) and non-artists (N=9) considered together. For artists vs. non-artists, this result holds at 2 of 3 levels of illusory contrast (i.e., the contrast of the luminance ramp in the center of the illusory stimulus). In addition, there is an inverse correlation between the subjects' reported number of hours spent painting or drawing per week and PSE for the same two illusory contrasts ($R_2 \geq .18$). Artistic training regimes—and perhaps innate endowments—that lead to the putative ability to judge luminance accurately may be seen as analogous to those that allow superior pitch judgment (e.g., absolute or relative pitch) in musicians, and therefore we provisionally term superior luminance judgment as absolute (or relative) value. Artists with this ability are of interest to vision science, much as musicians with superior pitch perception have long been studied by audition researchers to elucidate neural processing of acoustic tone. Tests aimed at determining the factors involved in artists' ability to judge luminance and tests quantifying luminance judgment in naturalistic conditions are also described.

16.535 **Biological computations underlying grouping-by-similarity in lightness perception**

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Lightness contrast and assimilation are both observed in matching experiments performed with disk-and-ring displays, where the two opposite-signed induction effects are part of a larger quantitative pattern in which lightness varies as a parabolic function of surround luminance (Rudd, JOV, in press). Here I show that a parabolic pattern is also obtained with manipulations of surround size; and that both parabolic effects result from a long-range perceptual grouping process. Specifically, target lightness varies as a function of the squared difference between the surround luminances (in log units), or surround widths, on the target and matching sides of the display. These squared differences reflect biological definitions of luminance and size similarity, respectively. The parabolic pattern is enhanced (i.e. grouping strength increases) when an observer is biased to see the target and matching disks as being co-illuminated, either by presenting the target and match configurations against a common white background or by instructing the observer to assume a common illuminant (with a black background). The parabolic pattern disappears when the observer is biased to see the disks as being separately illuminated by both presenting the configurations against a common black background and instructions to assume separate illuminants. With the black background, but no special instructions, the results are mixed. To account for the results, I propose a model in which the observer can adopt either of two strategies for matching the disks. If the two disks are interpreted as being independently illuminated, the observer adopts a ratio-matching strategy. If disks are interpreted as co-illuminated, the observer adopts a strategy involving long-range grouping. In the most general case, the matches are based on a weighted sum of the two strategies. Combining this model with the idea that visual similarity depends of squared differences accounts for the parabolic matching functions and lightness assimilation.

16.536 **Highlight disparity, surface curvature and perceived gloss**

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The presence of specular highlights can give rise to a perception of gloss that propagates across the surface. Under binocular viewing, the disparity of a specular highlight is dependent upon the sign and magnitude of surface curvature. Observers are somewhat sensitive to highlight disparity in perceiving surface gloss (e.g. Blake and Buelthoff (1990); Wendt et al., 2008, 2010). However, a comprehensive description of the relationship between the perceived sign and magnitude of surface curvature, the sign and magnitude of highlight disparity and the perceived gloss of a surface is missing. We asked observers to judge the glossiness of convex and concave surfaces. On each trial, the scene consisted of two partial spheres that protruded from a flat surface; one was rendered to be convex and one to be concave, relative to the observer. Surface shape was defined by both visual (shading, disparity) and haptic cues. A single specular highlight was present on one of the two objects. The highlight disparity varied in magnitude and sign from trial to trial. Subjects made gloss judgments using a continuous scale. Our results confirm that observers are sensitive to the magnitude of highlight disparity with smaller highlight disparities (relative to the surface disparity) reducing gloss perception. However, we find that observers are less sensitive to the sign of disparity than suggested by Blake and Buelthoff (1990).

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Perceptual learning: Plasticity and adaptation

Friday, May 6, 6:45 - 9:30 pm

Vista Ballroom, Poster Boards 537 - 546

16.537 **Separate mechanisms for long- and short-term contrast adaptation**

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Depriving the adult visual system of contrast at an orientation increases sensitivity to that orientation. Such contrast adaptation strengthens as the inducing period lengthens, with long periods producing longer-lasting effects. This could occur because over time, either a single mechanism gains strength, or additional long-term mechanisms become active. We tested between these alternatives by measuring effects of short-term adaptation before and after long-term adaptation. Subjects were deprived of vertical energy for 4 hours, viewing the world through an "altered reality" system comprised of a head mounted video camera, a computer, and a head-mounted display. Vertical energy was filtered from the video, allowing subjects to interact with the world while being deprived of an orientation. Following this long-term adaptation, which prior work has shown generates large adaptation effects, subjects "deadadapted" over the short-term by viewing unfiltered images for 15 min. Subjects then "readapted", viewing filtered images for 8 min. We measured effects of adaptation using the tilt aftereffect. An initial control period of adaptation, lasting 8 min, showed a weak tilt aftereffect of ~2 deg, lasting 100 sec. Following the four hours of adaptation and 15 min of deadadaptation, subjects showed no tilt aftereffect. However, the subsequent 8 min adaptation period generated a large, 3 deg aftereffect, that lasted over 5 min. Together, these results are inconsistent with a single mechanism controlling adaptation, because identical short-term adaptation periods generated different effects depending upon long-term adaptation history. The simplest account of our results is that 4 hours of adaptation produced effects in both short- and long-term mechanisms. Short-term deadadaptation then produced a negative effect that masked ongoing long-term adaptation. The 8-min readaptation reestablished the short-term effect and unmasked the long-term effect. Thus, deadadaptation and readaptation affected short-term adaptation independent of long-term adaptation, demonstrating that different time-scales are controlled by separate mechanisms.

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16.538 **The Eye-direction Aftereffect shows complete interocular transfer and is not retinocentric**

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For many aftereffects, adapting one eye while covering the other eye leads to an aftereffect in the covered eye. This is referred to as interocular transfer (IOT). IOT is seen with the tilt aftereffect, the motion aftereffect and the contrast threshold elevation aftereffect. The amount of IOT is often viewed as an indicator of the availability of binocularly-driven cells mediating the aftereffect. For most aftereffects, IOT is not 100%, an indicator of the presence of monocularly-driven cells. The present study assessed the amount of IOT for the Eye-direction Aftereffect (EDAE). While occluding one eye, observers viewed an adapting stimulus of an image of a face looking in one direction for 20s, followed by a test stimulus of the same face looking slightly off-center. On half the trials, the uncovered eye was used to measure the EDAE. On the other half, the occluder was removed from the unadapted eye to the adapted eye during the test phase. The EDAE was observed on all trials; following adaptation, the test images always appeared to be gazing at the center. The time required to dissipate the EDAE was recorded. The duration of the EDAE was, statistically, the same for both the adapted eye and the unadapted eye, indicating complete IOT. This finding favors the idea that the EDAE is mediated exclusively by binocularly-driven cells. In a second experiment, using both eyes, observers viewed the adapting stimulus for 20s by fixating on the nose and then looking at the forehead during test. The EDAE continued to be observed under these conditions, indicating that the EDAE is not retinocentric. These results of these two experiments are consistent with previous fMRI data suggesting that the aftereffect is mediated late in the visual pathway.

16.539 Effect of blur adaptation on contrast discrimination in emmetropes and myopes

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Studies have investigated visual resolution and contrast detection following a period of degradation in the retinal image (blur adaptation) and have shown it can produce increases in visual resolution and changes in contrast sensitivity. However these studies only explored a limited range of spatial frequencies of sine wave gratings or tested visual resolution alone. The current study aimed to expand on previous work by investigating contrast discrimination and contrast threshold sensitivity before and after blur adaptation for a range of different spatial frequencies. In addition both myopes and emmetropes were tested to see if they responded in different ways to the blur adaptation. Contrast discrimination thresholds were measured (monocular) for a range of spatial frequencies of sine wave gratings (0.5 to 24 cycles per degree) before and after adaptation to +2D blur (45 minutes of adaptation) in four emmetropes and four myopes (mean refraction -6DS). The contrast pedestal was set to 10% and an adaptive 2AFC procedure was employed. Contrast sensitivity and high contrast visual acuity were also measured before and after adaptation. The results showed increases in contrast sensitivity and contrast discrimination at some spatial frequencies after adaptation while others were reduced. In particular, the myopes showed the largest increases in mid to high spatial frequencies (16-20 cycles per degree) while emmetropes displayed reduced sensitivity at the higher spatial frequencies (18-24 cycles per degree). Measurements of the optics before and after adaptation ruled out any optical changes being responsible. The results therefore point to different neural adaptation strategies in the refractive groups. Possible models of how the visual system responds to periods of blur are discussed.

Acknowledgement: NSF BCS-0715076, NIH EY017678

16.540 Figural Chasers

Patricia Winkler¹(pwinkler2@unr.edu), Kyle C McDermott¹, Gideon Caplovitz¹, Michael Webster¹; ¹Department of Psychology, University of Nevada, Reno

In the lilac chaser illusion (Jeremy Hinton, en.wikipedia.org/wiki/Lilac_chaser), splotches of color in the periphery fade to invisibility so that the negative afterimage when each splotch is removed becomes the most conspicuous feature. The illusion provides a compelling illustration of adaptation processes in color vision and how they influence color salience. We explored spatial variants of the illusion to test for comparable effects of adaptation on the salience of visual form. Stimuli consisted of a central image corresponding to a spatial norm (analogous to gray) surrounded by peripheral images that were spatially distorted (analogous to color contrast). The norms and distortions included geometric figures (circle vs. ellipses), edges and texture (focused vs. blurred or sharpened images), and faces (normal vs. configurally distorted), with each distorted figure briefly and sequentially replaced with the norm. Observers fixated the center image and then rated the appearance of the steady-state distorted images or the undistorted transient relative to the norm. For each, moderately distorted images in the periphery tended to take on the appearance of the central figure, while the physically matched transient appeared as a strong spatial aftereffect (e.g. so that the physical ellipses appeared more circular while the circle appeared as an ellipse with the opposite orientation). These percepts are consistent with an adaptation effect that renormalizes the appearance of the peripheral distortion so that it appears more neutral, but may also include an effect of foveal capture on the appearance of peripheral stimuli. The analogous aftereffects for color and form suggest that "Troxlerville" fading in the periphery may occur for many stimulus dimensions and that these adaptation effects may generally enhance the salience of novel stimuli by discounting responses to the prevailing stimulus.

Acknowledgement: EY-10834

16.541 Examining the effects of stroboscopic vision

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Visual and attentional abilities can differ greatly from one individual to another, and within an individual over time. Most differences between individuals are deeply rooted (e.g., between those who suffer from ADHD and those who do not), and most ability changes for an individual over time

seem to arise from extensive, long-term training (e.g., perceptual learning effects, habitual video game playing). Relatively less evidence exists for more immediate improvements in visual cognition abilities through training procedures. Enhancement that can occur quickly could be highly valuable given the potential benefits of enhanced vision and attention in many arenas, including athletic activities. Athletes often must respond in millisecond time scales and any improvement in their ability to process incoming visual information has promise to enhance their performance. Using a new athletic training product that was presented at the 2010 Vision Sciences Society Demo Night, we provide evidence of improved visual abilities after training. Participants completed several computer-based visual cognition experiments (e.g., a motion coherence test) before and after engaging in training with simple sports activities (e.g., playing catch) while either wearing a new product called "Nike Strobes" or control eyewear. Nike Strobes are eyewear that use battery-powered liquid crystal stroboscopic filters (alternating between transparent and opaque) in the lenses to restrict incoming visual information and the control eyewear had clear lenses. Participants completed multiple 24-minute training sessions. Those who trained with the Nike Strobes showed greater improvements than those in the control group, revealing training benefits due to the stroboscopic experiences. The Strobe eyewear offer a potentially powerful visual training tool as they can be easily incorporated into normal activities and the strobe rate can be adjusted to progressively limit more incoming visual information.

Acknowledgement: Nike Inc.

16.542 Improvement in Stereoacuity through Training with Correlated Cues

Cristina Llerena Law^{1,2}(cllerenaod@gmail.com), Benjamin Backus^{1,2}, Baptiste Caziot^{1,2}; ¹Graduate Center for Vision Research, SUNY State College of Optometry, ²SUNY Eye Institute

Visual discrimination can improve with practice. For stereoacuity, 80% improvement in threshold have been reported (Fendick and Westheimer, Vision Research 1983). Here, we exploit the "cue recruitment" paradigm (Haijiang et al, PNAS 2006) during perceptual learning to improve stereoacuity. We used static occlusion cues that had varied reliability as "training wheels" to guide participants' use of disparity during the construction of perceived depth, which might in principle lead to better performance on a stereoacuity task. Stimuli were textured rectangles, one above the other, with varied horizontal offset. Subjects indicated which appeared closer and were given feedback. Four subjects were screened and assigned to one of two groups, "disparity-plus-occlusion" and "disparity-only". Half of the stimuli presented to the disparity-plus-occlusion group contained occlusion cues, and the remainder contained only disparity because the region of overlap was occluded. All stimuli for the disparity-only group contained only disparity. Each subject participated in three sessions lasting approximately 45 minutes, each containing 300 trials, on three non-successive days. In both groups, the same staircase procedure controlled the amount of disparity and monitored improvements in threshold based on responses from every other trial (always a disparity-only trial). Two of four subjects showed improvements in stereoacuity threshold on day three as compared to day one, but this improvement was recorded in one subject from each group. Thus, data collected to date do not suggest a positive correlation between improvements in stereoacuity thresholds and training with correlated cues in subjects with normal vision. Additional data may resolve this question. Furthermore, it could be clinically useful to add "training wheel" cues to accelerate improvement in visual function, for example, during vision training/orthoptics after surgical alignment of the eyes.

Acknowledgement: NIH R01 EY-013988, NIH Loan Repayment Grant to Dr. Llerena Law

16.543 Effects of meditation on consolidation of perceptual learning

Erika Scilipoti¹(erika.scilipoti@gmail.com), Takeo Watanabe¹; ¹Boston University
Meditative practices can enhance visuospatial working memory (Kozhevnikov et al., 2009) and sensory acuity (Kerr et al., 2005). It is thought that these effects are caused by enhanced attention to a given task, due to meditation. However, it is not clear whether meditation facilitates other forms of implicit processing that do not directly relate to attention. Here we investigated the effects of meditation on perceptual learning stabilization that occurs after training on a texture discrimination task (TDT) (Karni and Sagi, 1992). Zen meditators and non-meditators were trained in TDT. Previous studies have reported that learning of TDT with a background orientation (training A) is impaired by subsequent learning of TDT with

a different background orientation (training B) (Yotsumoto et al., 2009). It is thought that such impairment is due to the interference effects of training B on the consolidation/stabilization processes of training A (Shadmehr and Holcomb, 1997; Seitz et al., 2005). We examined whether this interference effect could be reduced or overcome by meditation. Participants completed a total of ten sessions that were administered in five consecutive days. Within each day, successive sessions consisted of two training conditions, A and B, that were separated by a 20 minute interval, during which participants were instructed to engage in either meditation or relaxation ("mind-wandering"). The two training conditions differed only in the orientation of background elements. The results show that the amount of interference was smaller for the meditation group compared to relaxation controls. These results suggest that meditation enhances the consolidation process of perceptual learning.

Acknowledgement: NIH R01 (EY015980, EY019466, AG031941, MH091801)

16.544 Perceptual learning solely induced by feedback

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While perceptual learning (PL) is facilitated by feedback such as the correctness of a subject's response (response feedback), it can occur even without any feedback (e.g. Karni & Sagi, 1991; Poggio et al, 1992; Watanabe et al, 2001). Thus, response feedback has been considered to play a superfluous role in PL. However, recently it has been found that mere top-down processing, such as imagination, could induce PL (Dupuis-Roy & Gosselin, 2007; Taglia et al, 2009). This finding implies that response feedback could play a more important role than has been thought. To test this hypothesis, we conducted a seven-day experiment that employed an oriented sinusoidal grating (signal) embedded in spatial noise (noise). During five days of training, subjects were asked to identify the orientation of a grating patch by choosing one of two given orientations (2AFC). Each orientation was exclusively associated with one of the two conditions, one with the signal condition wherein an actual stimulus was presented, and the other with the noise condition wherein only noise was presented without any actual stimulus. Response feedback was provided after each trial in both conditions. Note that, in the noise condition, response feedback was fake feedback because no orientation was actually presented. Since the grating patch in the signal condition had 5% signal to noise ratio, with which subjects could hardly identify the grating, subjects could not discriminate between the two conditions. After training, subjects' sensitivity improved not only towards the orientation in the signal condition, but also towards the orientation indicated by fake feedback in the noise condition. These results indicate that response feedback itself can solely induce PL. They further imply that there are at least two types of PL, one by feedback and the other by exposure to a feature, with mechanisms distinguishable from each other.

Acknowledgement: NIH R01 (EY015980, EY019466, AG031941, MH091801)

16.545 Effects of Visual Deprivation on Regional Cerebral Blood Flow Velocity and Neurovascular Coupling

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Recently, short-term visual deprivation has been shown to affect a variety of non-visual processes and regional cortical activity (Sathian & Zangaladze, 2001). Surprisingly, very little is known about how such visual deprivation impacts regional cerebral blood flow velocity (CBFv) or its adaptation with the underlying neuronal activity (i.e., neurovascular coupling). The current study sought to investigate the effects of short-term (two-hour) visual deprivation on regional CBFv and neurovascular coupling. CBFv (transcranial Doppler ultrasound) was measured concurrently in the posterior cerebral artery (PCA) and the middle cerebral artery (MCA). Neurovascular coupling was assessed using established methods, consisting of two minutes of baseline (eyes closed and reading), five cycles of 40 seconds reading - 20 seconds eyes-closed (primary protocol), and five cycles of 40 seconds eyes-moving - 20 seconds eyes-closed (secondary protocol). Neurovascular coupling, using both protocols, was collected before and following a two-hour visual deprivation (black out) protocol whilst both regional CBFv and secondary neurovascular coupling protocol was measured at thirty-minute intervals throughout deprivation. Baseline measures indicated mean MCAv decreased 7.36% as a function of visual deprivation while PCAv showed the reciprocal effect, increasing 8.2% with differences arising via systolic peaks on both arteries. The primary (reading/closed) neurovas-

cular-coupling protocol revealed post-deprivation decreases in MCAv of 9.32% while the secondary (moving/closed) protocol also decreased MCAv 12.5% as a function of deprivation. In addition, the secondary (moving/closed) protocol elicited systematic decreases in both systolic and diastolic peaks of PCAv across the 30, 60, and 90-minute intervals of visual deprivation. Short-term visual deprivation has been shown to differentially affect regional CBFv. Moreover, variations in blood flow provide further insight regarding visual processing, attenuation, and neurovascular coupling.

Acknowledgement: NSERC, CFI

16.546 Two perceptual consequences of orientation discrimination learning and their distinct time courses

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Perceptual learning can improve sensory discrimination and the improvement is long-lasting. Here we show that orientation learning can not only improve orientation sensitivity, but also affect our judgement of absolute orientation. Eight subjects were trained to discriminate orientation at 15°. After six daily training sessions (over 8000 trials practice), as expected, subjects showed a significant orientation-specific improvement at the trained orientation. Before and after training, we also measured their subjective vertical orientation. Interestingly, training was able to render the subjective vertical orientation perceived to shift towards the trained orientation, which resembled the well-known tilt aftereffect. The change of subjective vertical orientation after training was highly specific to the trained retinal location. It was also dependent on the trained orientation since data from other eight subjects showed that training at 75° had little effect on their subjective vertical orientation. Regarding the time course of these two perceptual consequences, although orientation discrimination improvement was completely preserved two months after training, the change of subjective vertical orientation substantially diminished. In addition, we conducted an exposure experiment that was identical to the 15° orientation discrimination experiment except that subjects did a simple fixation task. Although subjects' orientation sensitivity remained the same, their subjective vertical orientation significantly shifted towards the exposed orientation (15°). These results demonstrated a clear dissociation between orientation discrimination improvement and subjective orientation change, which compels us to re-evaluate the role of the early visual cortex in orientation discrimination learning. Although learning (even exposure) may have changed the orientation coding in the early visual cortex, which altered the subjective vertical orientation, the orientation coding change might have nothing to do with the perceptual learning of orientation discrimination. The neural substrate of orientation discrimination learning could be in high-level cortical areas (e.g. decision making areas).

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Saturday Morning Talks

Saturday AM

Color and light: Surfaces and materials

Saturday, May 7, 8:00 - 9:45 am

Talk Session, Royal Palm 1-3

Moderator: Anya Hurlbert

21.11, 8:00 am

At what level of representation is surface gloss computed?

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We recently argued that the perception of gloss depends on the congruence between computations of 3D shape and the locations of highlights, and showed that displacements of highlights in the image plane destroyed the perception of gloss. Here, a series of experiments were conducted to further assess this congruence hypothesis by manipulating highlight locations in 3D. We rendered bumpy spherical surfaces using natural illumination fields. The specular and diffuse reflectance components were decomposed and stored as separate 3D maps. In Experiment 1, the specular and diffuse shading maps were rotated relative to each other in 3D by varying degrees and then additively combined, introducing "phase shifts" between the diffuse and specular reflectance maps. In Experiment 2, we introduced highlight incongruences by rotating the illumination field of the diffuse reflectance component (only) by varying degrees. In Experiment 3, we combined these two sources of incongruence, introducing both "phase shifts" and illumination field misalignments between the diffuse and specular reflectance components. Observers were shown pairs of stimuli and reported which image appeared glossier, for both static and moving displays. The results of these experiments demonstrated that the percept of gloss decreased monotonically as a function of highlight misalignment. In Experiment 1, the decline in perceived gloss with phase shift misalignment dropped off steeply for small misalignments, and asymptoted quickly, particularly for the moving images. The decline in perceived gloss with the illumination field rotation generated a nearly linear decline over the full 180 degrees of rotation for both static and moving images, and dominated the effects of phase offset when the two sources of incongruence were combined in Experiment 3. The results of these experiments provide strong evidence that the computations responsible for the perception of surface gloss occur in a 3D representational space, which cannot be understood with 2D image statistics.

Acknowledgement: ARC

21.12, 8:15 am

Luminance-color interactions in surface gloss perception

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Light reflection of glossy dielectric materials consists of specular and diffuse components. The spectral distribution of illumination is preserved in the specular reflection, while modulated by surface light absorption for the diffuse reflection. This leads to the following physical constraint: the specular spectral distribution should include the diffuse spectral distribution, and highlights (specular + diffuse) should be brighter than the surrounds (diffuse only) when seen through any narrow band filter. By changing the color combination of specular and diffuse components, we have shown that human observers perceive naturalistic glossy surfaces when the physical constraint holds (e.g., red highlights on red body, white on red), but not otherwise (e.g., red on white, red on green) (Nishida et al., VSS2008). We further observed that even if the color combination is valid (e.g., white on red), the gloss perception is lost when highlights have no luminance increments. A hypothesis of gloss computation consistent with the physical constraint and the observed perceptual effects is to decompose the image into multiple color bands, and run achromatic gloss analysis at each band. We tested this idea with using L-cone, M-cone and S-cone images as biologically plausible band images. We made a display in which the L- and M-cone images contained a glossy object with natural bright highlights, while the S-cone image the same object with unnatural dark highlights. The resulting image violated the physical constraint, but the display looked naturally glossy when the S-cone image intensity was adjusted so as to render

highlights apparently white. The S-cone image was not simply discarded, since the display looked unnatural with different S-cone image intensities. Multiple color band analysis is a promising hypothesis of luminance-color interactions, but our observation indicates that the simplest version using raw cone images cannot fully explain the luminance-color interaction in gloss perception.

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21.13, 8:30 am

Shape modulates the effect of lightfield on perceived glossiness

Maria Olkkonen¹(mariaol@sas.upenn.edu), David Brainard¹; ¹Department of Psychology, University of Pennsylvania

PURPOSE. Object surface reflectance can be approximated as arising from two components: the diffuse component, which correlates with perceived lightness and color, and the specular component, which correlates with perceived glossiness. In addition to the reflectance parameters, geometric and spectral properties of the illuminant as well as object shape affect the spectrum and geometry of the reflected light. We and others have shown that lightfield geometry affects the perceived glossiness of spheres. Here, we study the interaction between changing the lightfield and changing object shape on perceived glossiness. **METHODS.** The stimuli consisted of two different blob-shaped objects with both convex and concave regions. These were rendered under three different natural lightfields using the Radiance rendering software. On each trial, a pair of objects were presented side-by-side on a high-dynamic-range display. Observers indicated which object appeared glossier, and an adaptive staircase procedure adjusted the strength of the specular reflectance component over trials to determine the point of subjective equality. We examined the effect of changing lightfield and the effect of changing shape. Measurements were made for three levels of reference specular reflectance, and the effect of lightfield and shape was quantified by the slope of the line fit to the reference specularity versus PSE data. **RESULTS.** Changes in lightfield and shape both had substantial effects on perceived glossiness: measured slopes deviated from unity by an average (across subjects) of 51% (lightfield) and 66% (shape). In addition, there was a strong interaction between shape and the effect of lightfield. For one of the lightfield changes, the effect on perceived glossiness had opposite sign for the two shapes: the average slope for Shape A was 1.95 but for Shape B was 0.56. Thus to develop a theory of perceived glossiness, effects of lightfield and object shape must be considered jointly.

Acknowledgement: Supported by NIH Grants R01 EY10016 and P30 EY001583

21.14, 8:45 am

3D surface shape and the appearance of glow

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Why do objects appear to glow? Previous studies on perception of glow have focused on simple 2D stimuli, largely neglecting the contribution of 3D shape cues. Here we show that 3D surface shape plays a crucial role in glow perception, and advance a theory of what luminance and shape patterns induce a percept of glow. **HYPOTHESIS.** For non-glowing objects under diffuse light, the luminance of a surface patch depends on the amount of the light source visible from the patch; thus, patches are dark in valleys and bright on peaks (Langer & Bülthoff, 2000). For glowing objects, the luminance depends on the amount of light received from neighboring glowing surfaces; thus, patches are bright in valleys, and dark on peaks. That is, brightness and depth are negatively correlated for diffusely lit objects, and positively correlated for glowing objects. In our experiment, we examined whether manipulating this shape-and-luminance relationship could generate apparent glow. **METHODS.** We rendered objects with complex, wavy surfaces under purely direct and purely diffuse lighting, and then inverted the luminance of the diffuse image to obtain the inverted diffuse image. The stimulus was a weighted sum of the three components (direct, diffuse, and inverted diffuse). Observers viewed pairs of stimuli generated with different inverted diffuse weights, and chose the object with stronger perceived glow. **RESULTS.** A Thurstone scaling analysis of the paired comparison responses revealed that diffuse inversion can induce apparent glow, and that higher inverted diffuse weights lead to stronger glow. Our

results show that the perceived relationship between surface depth and luminance is relevant to perceived glow in complex objects, and further suggests the possibility that glow may be modulated by higher-order 3D shape cues (e.g., curvature).

Acknowledgement: NSERC, CFI

21.15, 9:00 am

The intrinsic colour of transparent materials

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As light travels through a transparent material, such as bottle glass, some proportion of the light is absorbed. The absorption is often wavelength dependent, giving these materials a certain colour. The further light travels through the material, the more is absorbed, making the emerging light progressively darker and more saturated the further it travels. This poses the visual system with a colour constancy problem that has not been considered previously, and which cannot be explained by current theories of perceptual transparency. Specifically, to estimate the intrinsic spectral transmissivity of the material, the visual system must compensate for the effects of the thickness of the piece of material. To what extent do we compensate for thickness? Which image measurements do we use to estimate transmissivity? We show that this novel colour constancy problem is theoretically more constrained than standard colour constancy, because thickness cannot affect hue, and because saturation and intensity tend to be negatively correlated with one another. Using computer simulations of glass-like materials we measured the extent to which subjects compensate for thickness when judging opacity in an asymmetric matching task. Subjects matched the colour of two glass-like pebbles that differed in thickness. We find that subjects' estimates of intrinsic colour are systematically affected by thickness, showing that they cannot completely compensate for it. In a second experiment using multi-dimensional scaling, we find that thickness and opacity are distinct but interacting perceptual dimensions. The range of apparent opacities increases with thickness, much as the range of apparent lightness increases with perceived illumination (Logvinenko and Maloney, 2006). We compare the results to the predictions of several low- and mid-level image measurements. The findings suggest a novel theory of how HSV colour space can be used for separating image colours into physical causes, of which transparency is just a special case.

Acknowledgement: RF supported by DFG FL 624/1-1

21.16, 9:15 am

The effect of shape and chromatic texture diagnosticity on color discrimination of natural objects

Milena Vurro¹(milena_vurro@harvard.edu), Anya Hurlbert²; ¹Massachusetts General Hospital, Harvard Medical School, ²Institute of Neuroscience, Newcastle University

Many natural objects possess distinctive surface textures as well as shapes, both of which may serve as cues to object identity. Previously, we showed that the presence of natural chromatic texture and shape cues improved the accuracy and precision of memory color for natural objects [Vurro et al., VSS 2008]. Here, we investigate the effect of the diagnosticity and congruency of chromatic texture and shape on color discrimination of natural objects. We performed two experiments; subject's task was to match a test stimulus from two alternatives, presented either simultaneously (Experiment 1) or successively (Experiment 2) relative to the test stimulus. Six familiar fruits and vegetables were employed to generate the stimuli: apple, banana, carrot, cucumber, lime, and potato. For each object, three chromatic surfaces were used: (1) natural surface texture; (2) spatially scrambled version of the texture preserving its chromatic content; or (3) uniform surface with the texture's mean color. Each chromatic surface was combined with each of three 3D solid shapes: congruent (e.g. apple texture on apple shape); incongruent (e.g. lime texture on banana shape); or generic (e.g. carrot texture on rhomboid shape). On each trial, alternatives varied only in the mean hue angle of the surface chromaticity distribution. Simultaneous angular discrimination thresholds were significantly higher for chromatically variegated surfaces relative to uniform surfaces, and for incongruent shapes relative to congruent or generic. Successive discriminations were easier and faster for natural textures compared to uniform surfaces or scrambled textures, as were natural shapes compared to generic shapes. The results indicate a low-level mechanism, responsible for chromatic variegation generally degrading simultaneous hue discrimination, as well as a high-level mechanism, responsible for diagnostic chromatic texture and congruent

shape improving successive hue discrimination. The latter effect suggests that memory color is linked to shape and incorporates representations of the natural spatio-chromatic texture.

Acknowledgement: Supported by EPSRC (Project EP/D068738/1).

21.17, 9:30 am

Material recognition is fast, but not superfast

Edward Adelson¹(adelson@ai.mit.edu), Lavanya Sharan², Ruth Rosenholtz¹; ¹Brain and Cognitive Sciences & CSAIL, MIT, ²Disney Research, Pittsburgh

We have previously shown that high-level material categories can be recognized in complex, real world images in exposures as brief as 40msec (Sharan et al., 2009). This performance is comparable to recent results in rapid object and scene categorization (Bacon-Mace et al., 2005; Greene & Oliva, 2009). We now have studied the speed of object categorization versus material categorization more directly. We collected a database of photographs containing two classes of objects (gloves vs. handbags) that were made from two classes of material (leather vs. fabric). There were a total of 200 images, with 50 examples for each combination of object and material. In a 2AFC task, subjects viewed one image at a time, and categorized each image. For 100 images, the task was object categorization; for the other 100 images it was material categorization. We also ran two baseline RT tasks: telling a blue disc from a red disc, and telling a left tilting line from a right tilting line. We then compared object RT's with Material RT's. As expected, the baseline tasks were the fastest, with a median RT of 390msec. The object task was slower, but the median RT was only about 50msec slower than baseline. The material task was slower still, with a median RT more than 150msec slower than baseline. Since material perception is a complex task (for which we have no good models), 150msec seems reasonably fast. However, 50msec is even faster. In a task like this, the precise ratio of the incremental RT's has limited meaning, since one can bias the results by choosing images that are easy or hard on one of the dimensions. However, the 3:1 ratio of incremental RT's for these two tasks is hard to dismiss, and provides clear evidence that object recognition is a faster process than material recognition.

Acknowledgement: NIH, NSF

Attention: Features and objects

Saturday, May 7, 8:00 - 9:45 am

Talk Session, Royal Palm 4-5

Moderator: Miranda Scolarì

21.21, 8:00 am

Individual differences in object-based attention effects in discrimination and detection tasks

Karin S. Pilz¹(pilzk@mcmaster.ca), Alexa B. Roggeveen², Sarah E. Creighton¹, Patrick J. Bennett^{1,3}, Allison B. Sekuler^{1,3}; ¹Department of Psychology, Neuroscience and Behaviour, McMaster University, Canada, ²Sheridan Elder Research Centre, Sheridan Institute of Technology and Advanced Learning, Canada, ³Centre for Vision Research, York University, Canada

It has been long suggested that attention can be allocated to both space and objects.

Previously, Roggeveen et al. (VSS 2008) used a target discrimination task (Moore, Yantis, & Vaughan, 1998) to investigate individual differences in object-based attention (OBA) for both vertical and horizontal objects. Interestingly, although we found evidence of space based attention in both orientations, we found OBA only for horizontal objects.

One limitation of Roggeveen's study is that only discrimination tasks were tested, while most OBA research has focused on detection. Here we directly compare results for 60 observers tested in tasks involving both target discrimination and target detection (Egley, Driver and Rafal, 1994). In general, RTs were much shorter for the detection task. For target discrimination we found the same pattern of results as described before: OBA for horizontal objects and opposite effects for vertical ones. For target detection, OBA was more pronounced for horizontal objects, but the trend was in the same direction for vertical objects. These results underline orientation effects may exist in multiple tasks, and that OBA is generally stronger for horizontal objects.

Previous research has suggested that performance in a variety of visual tasks is better on the horizontal than the vertical meridian (e.g., Carrasco Talgar, Cameron, 2001). Such attentional preferences could explain why OBA in the current study was generally more pronounced for horizontal objects.

Finally, given our large sample size, we were able to use bootstrapping to estimate effect sizes for individual subjects. We found high degrees of variability among subjects across both tasks and orientations. Whereas more than 80% of observers exhibited significant space-based attention effects, fewer than 10% of the observers in each task and orientation showed significant OBA. Taken as a whole, these results suggest that OBA might not be as robust and ubiquitous as previously assumed.

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21.22, 8:15 am

The speed of intentional control over bistable apparent motion

Julia Mossbridge¹(j-mossbridge@northwestern.edu), Marcia Grabowecky^{1,2}, Satoru Suzuki^{1,2}; ¹Department of Psychology, Northwestern University, ²Interdepartmental Neuroscience program, Northwestern University

How much time does it take to voluntarily control the perception of bistable apparent motion? Addressing this issue could shed light on the dynamics of the intentional control of perception. We used tones to cue participants to engage their intentional control over the subsequently presented bistable rotation. The initial stimulus consisted of a pair of dots either vertically or horizontally arranged around the center of mass. In each trial, an auditory cue (a 300Hz or 600Hz tone) was presented, and after a variable delay (up to 1s) the initial stimulus was replaced by its orthogonally arranged version. The change in the orientation of the dot arrangement caused a bistable percept of either clockwise or counterclockwise rotation. Participants were told to intend to see counterclockwise rotation after hearing the 300Hz tone, and clockwise rotation after hearing the 600Hz tone, then to report the actual direction of perceived rotation. As the delay between the auditory cue and the rotation onset became shorter, the ability to intentionally control perception decreased smoothly to near chance at no delay, but remained above chance at 200 ms. In a second experiment, we further demonstrated that the minimum time required for intentional control might be affected by subjective time. In this experiment, half of the trials were preceded by adaptation to a 5-s 5Hz flicker known to cause subjective temporal dilation while the remaining trials were preceded by adaptation to a static stimulus. At the 0 ms cue-to-rotation delay, flicker adaptation resulted in significantly superior intentional control than did static adaptation. The systematic dependence of the intention effects on the cue-to-rotation delay and flicker adaptation precluded explanations based on response bias. In summary, intentional control of apparent motion requires less than 200 ms preparation, and its underlying mechanisms might be susceptible to factors affecting subjective time.

Acknowledgement: NIH R01 EY018197, NSF BCS 0643191

21.23, 8:30 am

Testing the flexibility of top-down attentional gain in early visual cortex.

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Traditional accounts of selective attention hold that top-down mechanisms increase the gain of sensory neurons tuned to behaviorally relevant stimuli in order to facilitate perception. Recent theoretical and psychophysics studies suggest that selective attention operates more flexibly by targeting the most informative neurons, which—depending on task demands—are not always the most responsive (e.g., Navalpakkam and Itti, 2007; Scolari and Serences, 2009). For example, neurons tuned away from the target (off-channel neurons) are particularly informative when performing a difficult discrimination between two similarly oriented gratings. Furthermore, we previously showed that relatively higher off-channel activation in V1 predicted performance on a difficult discrimination task. However, given that attention was not manipulated here, two distinct models may account for these results. First, top-down attention might target off-channel neurons, increasing the amount of information available to downstream decision mechanisms (early gain account). Second, downstream decision mechanisms may favorably weight sensory input from informative off-channel

neurons during decision-making in the absence of attentionally-modulated firing rate changes in early visual cortex (optimal read-out account). The current study tested these competing hypotheses using fMRI and a forward 'encoding model' to measure feature-selective modulations in early visual areas. Subjects performed either a difficult orientation discrimination task, contrast discrimination task, or rapid serial visual presentation letter task at fixation. Directing attention to the difficult orientation task resulted in a multiplicative scaling of feature-tuning functions in V1-V3v such that the activation of neural populations tuned to the target was enhanced. Contrary to our predictions, no evidence of top-down off-channel gain was observed. However, trial-by-trial fluctuations in the activation level of off-channel responses predicted perceptual decisions. Together, these results support the optimal read-out account: top-down attention inflexibly targets the most active sensory neurons, but downstream decision-related mechanisms dynamically read-out information from the most informative neurons based on task demands.

21.24, 8:45 am

Feature-based attention enhances performance by increasing response gain

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Objective: Characterize the contrast dependence of feature-based attention.

Methods: Observers performed a 2IFC orientation-discrimination task. The first interval contained 32 randomly positioned Gabors (16 had identical orientation thetaR near 45° and 16 had identical orientation thetaL near -45°). In the second interval, 32 Gabors all shared identical orientation thetaT chosen randomly from thetaR ± 1 JND or thetaL ± 1 JND. Observers indicated whether thetaT was slightly clockwise or counter-clockwise of the corresponding orientation (thetaR or thetaL) in the first interval. Feature-based attention was manipulated with a 75%-valid pre-cue (a ±45° line at fixation) resulting in valid (pre-cue and thetaT roughly matched) and invalid (mismatched) cue conditions. The precise values of thetaR and thetaL were randomly and independently varied over trials so that the first-interval display was uninformative as to which orientation would be queried. Performance (d') was measured for each cue condition and several contrasts, randomly interleaved.

Results: We fit psychometric functions with five free parameters (full model) to the data: asymptotic performance at high contrast (d'max) for each cue condition, contrast yielding half-maximum performance (c50) for each cue condition, and an exponent shared by both cue conditions. Feature-based attention significantly changed d'max, but not c50. Nested F-tests showed a similarly good fit of a restricted model using one c50 for both cue conditions (compared to the full model). A restricted model with one d'max for both cue conditions fit significantly worse than to the full model. Conclusion: We manipulated feature-based attention while minimizing effects of spatial attention. Our results are consistent with an increase in response gain and support a key prediction of the normalization model of attention (Figure 4c of Reynolds & Heeger, Neuron, 2009).

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21.25, 9:00 am

Different attentional strategies are reflected by modulations in the feature tuned flicker response

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Attentional modulations in early sensory areas (such as striate and extrastriate cortex) arise in part from activity within parietal locations involved in attentional control. However, the influence of attention on parietal responses to unattended stimuli is relatively unexplored. We measured parietal SSVEP responses to an unattended left visual field flickering grating (F2=8 or 12 Hz) while individuals (n=11) attended to orientations that were offset by 0, 10, 20, 30, 40 and 90 degrees from the orientation of the unattended flicker. These attentional tuning curves were measured during Detection, Fine Discrimination, or Coarse Discrimination of Gabor's. Differences in attentional strategies encouraged by each task may be reflected by differences in the attentional tuning curves. We found that during Detection there is a monotonic decline in the SSVEP response to the unattended 8 Hz flicker as the attended orientation is shifted 0, 10, 20, and 30 degree off-

set from the flicker orientation. This monotonic decline is not present when individual's discriminate the target from an orthogonal target (Coarse Discrimination). The monotonic decline is present during Fine Discrimination with a broader fall-off compared to Detection. Few attentional modulations were observed with a 12 Hz flicker. These differences in the 8 Hz attentional tuning curves likely reflect the degree in which attentional gain is applied over a range of orientations during each task. During Detection individuals appear to apply the sharpest gain on the attended orientation. When discriminating between another Gabor oriented 90 degrees away (Coarse Discrimination) attentional gain is flattened. Finally, attentional tuning during Fine Discrimination is intermediate, resulting from either a broadening of attentional gain or an increased gain applied to orientations that are off-center from the two potential targets. Thus, parietal SSVEP responses to an unattended flickering grating (8 Hz) are modulated by attended orientation, and are sensitive to attentional strategies.

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21.26, 9:15 am

Feature-based enhancement of visual stimuli at task-irrelevant locations

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The visual system selects inputs for extended processing on the basis of their features or locations. To date, considerable research has investigated the mechanisms underlying both featural and spatial selection, yet the extent to which these processes interact remains unknown. Here, we tested whether feature-based attention acts independently of spatial location by examining whether a featural set applies at locations that are completely task-irrelevant (i.e., outside the focus of spatial attention). In blocks of trials, observers monitored central vision for target letters in a cued color (red or green) that appeared within multi-letter arrays. Within each array, the target was defined either by a unique color (unique feature search) or by a combination of color and shape (conjunction search). The letter arrays were surrounded by colored checkerboards in peripheral vision that were always task-irrelevant and could therefore be ignored throughout the experiment. We used 'frequency tagging' in which flickering stimuli produce cortical oscillations at the flicker frequency, detectable at the scalp via electroencephalography (EEG). This approach allowed us to distinguish neural responses evoked by the task-relevant central stream from activity related to the task-irrelevant peripheral checkerboards. The checkerboard stimuli contained interleaved elements of three different colors: those that matched the target color, those that matched the distractor color, and those of a third, neutral color. During unique feature search, the magnitude of checkerboard-evoked brain oscillations was independent of the search color. During conjunction search, however, we found that checkerboard elements matching the target color evoked enhanced cortical oscillations relative to those associated with distractor or neutral colors. These results provide strong evidence that feature-based attention applies globally across the visual field, irrespective of the current focus of spatial attention.

21.27, 9:30 am

Understanding the Allocation of Attention when Faced with Varying Perceptual Load in Partial Report: A Computational Approach

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The allocation of visual processing capacity is a key topic in visual attention. Load Theory (LT, Lavie, 1995) proposes that allocation happens in two stages where resources are allocated to task-relevant stimuli in the first stage and any remaining capacity 'spills over' to task-irrelevant stimuli in the second stage. In contrast, the Theory of Visual Attention (TVA, Bundesen, 1990) proposes that allocation happens in a single step where capacity is allocated to all stimuli, both task-relevant and task-irrelevant, in proportion to their relative attentional weight. These models have three key differences: 1) LT predicts no effect of similarity between the task-irrelevant distractors and the target, TVA does; 2) LT predicts no effect of the number of task-irrelevant distractors, TVA does; and 3) LT predicts no change in performance when task-irrelevant distractors are absent, TVA does. We tested these divergent predictions in two partial report experiments in which the number and discriminability of task-irrelevant stimuli (Experi-

ment 1) and perceptual load (Experiment 2) were manipulated. The results of Experiment 1 revealed performance decrements when the number of flankers was increased and performance enhancements when the discriminability between the target and the flankers was increased. The results of Experiment 2 replicated and extended the findings of Experiment 1, while also showing nonlinear interaction between the effects of perceptual load and the number of task-irrelevant flankers. Quantitative TVA model fits captured the patterns in the behavioral data, while also showing that the effects of varying perceptual load can only be explained by a combined effect of allocation of processing capacity as well as limits in visual working memory. Considered together our behavioral and computational modeling results are inconsistent with two-stage allocation scheme proposed by LT, but rather are consistent with the straightforward predictions made by the single stage allocation scheme proposed by TVA.

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Spatial vision: Crowding

Saturday, May 7, 10:45 - 12:30 pm

Talk Session, Royal Palm 1-3

Moderator: Susana Chung

22.11, 10:45 am

No evidence for compulsory integration in visual crowding

Edward Ester¹(eester@uoregon.edu), Daniel Klee¹, Edward Awh¹; ¹Department of Psychology, University of Oregon

Items in the periphery of a visual display are more difficult to identify when flanked by irrelevant distractors, a phenomenon referred to as visual crowding. One perspective argues that crowding results from a compulsory averaging or integration of target and distractor features (the "integration" view). For example, although subjects are typically unable to report the orientation of a crowded stimulus, they can reliably estimate the average orientation of all stimuli in the display. This implies that local orientation signals are pooled or integrated prior to reaching awareness. An alternative perspective (the "swapping" view) argues that crowding results from a loss of positional information that leads the visual system to bind targets and distractors to incorrect spatial locations. For example, when asked to report the identity of a letter in a crowded display, subjects frequently report neighboring distractors with high confidence. Here, we attempted to distinguish between integration and swapping accounts of crowding using an analytical procedure that allowed us to simultaneously quantify the strength of distractor-target integration and the frequency of distractor-target swapping. Subjects were required to report the orientation of a parafoveal target that appeared in isolation or flanked by two oriented distractors. Subjects' estimates of orientation were used to define a distribution of response errors (i.e., reported minus actual orientation) which we attempted to describe using quantitative models that encapsulate key predictions of the integration and swapping perspectives. Across three experiments, we found no evidence for distractor-target integration. Instead, the majority of subjects' response errors were distributed around the target orientation, with the remaining responses normally distributed around distractor orientations or randomly distributed across orientation space. These findings are inconsistent with an integration account of crowding, and suggest that crowding primarily results from (1) a total loss of target information, or (2) swapping of target and distractor values.

Acknowledgement: Supported by NIH-R01MH077105-01A2 to E.A.

22.12, 11:00 am

Changes in crowding zone at the eccentric retinal loci of subjects with simulated central scotoma

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Crowding refers to the inability to identify an object when it is presented in clutter. Nandy and Tjan (2009, SfN) proposed that crowding is due to erroneously estimated image statistics acquired during saccadic eye movements, under the yet-to-be extinguished spotlight of attention that initiated the saccade. Changes in the patterns of saccades might therefore result in corresponding changes in the size and shape of crowding zones. An eccen-

tric retinal location can become the preferred retinal locus (PRL) for landing saccades and for fixations as a result of central scotoma. Nandy and Tjan (2010, VSS) predicted that the crowding zone at such a PRL would become smaller and rounder than a normal crowding zone at the same eccentricity, which is elongated along the radial direction relative to the fovea.

We tested this prediction using a gaze-contingent display to simulate a 10-degree central scotoma. Normally-sighted subjects performed demanding visual-search and object-tracking tasks for up to 15 hours (spread over weeks) without any instructions on how to use their peripheral vision. Three of four subjects developed a single PRL. For these three subjects, the landing site of the first saccade in the object-tracking task was close to the PRL and away from the fovea, suggesting the saccades had been re-referenced to the PRL. At the end of the experiment, subjects' crowding zones were measured with letter stimuli at their PRLs. We also measured crowding zones of four control subjects who did not participate in the experiment.

Consistent with the crowding theory of Nandy and Tjan (2009, 2010), the size of the crowding zone at the PRL was significantly smaller (55%) and its aspect ratio indistinguishable from being round (1.0). These findings support the idea that a change in saccadic eye movements can bring about functional changes in peripheral vision, particularly at the PRL.

Acknowledgement: National Institutes of Health Grants R01-EY017707, R01-EY016093.

22.13, 11:15 am

Target and flanker perception are related in crowded letter identification

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Crowding refers to the inability to recognize an object in the presence of other objects. One account of crowding is that it results from an inappropriate integration of features from the target and its flankers. There is evidence that the inappropriate integration is partly due to feature migration – features from the flankers are mislocalized from their veridical locations and are incorrectly considered as part of the target. This theory predicts that when several objects are present together, parts of each object could migrate, causing a simultaneous failure to recognize different objects. To test this prediction, we measured letter identification accuracy in seven normally-sighted observers. On each trial, three lowercase letters rendered at normal letter spacing were presented at 10° below fixation. Observers' task was to name the three letters. We analyzed the trials with respect to the presence of four basic letter structures (ascenders, descenders, round and oblique segments) in the stimuli and observers' responses. Across 44100 trials, the accuracy of identifying the flanked middle letters was 64% when both flankers were correctly identified, 36% when only one flanker was correctly identified and 20% when neither flanker was correctly identified. Further, for a pair of incorrectly identified adjacent letters, if the response to one of the letters did not include a specific letter structure that was present in the stimulus, this structure was found in the response to the adjacent letter in 59% of the trials. In contrast, when the response letter contained the correct letter structure, this structure was present in the response to the adjacent letter in only 19% of the trials. These results are consistent with the feature migration account of inappropriate feature integration and suggest that the identification of different objects in a crowded scene consists of an attempt to assemble features that are ambiguously localized.

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22.14, 11:30 am

Crowding reveals a third stage of object recognition

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How do we recognize objects? This simple everyday task has befuddled scientists for centuries. Research has led to a two-stage theory. First, visual features, such as color and orientation, are detected. Next, these features are combined. Here we ask which features are combined. Crowding is excessive feature combination that occurs when a target object is flanked by other objects, making the target impossible to identify. Exploiting the Gestalt laws, we manipulate proximity, similarity, closure, and regularity

(a component of continuity) in a crowding paradigm. We find that decreasing proximity, decreasing similarity, breaking closure, and decreasing regularity each dramatically reduces crowding (or feature combination). The Gestalt laws are simple principles of visual organization that describe how objects group with each other. We find that they also specify which features are passed from the detection stage to the combination stage of object recognition. We conclude that this process is a distinct grouping stage. There are not two, but three stages in object recognition.

22.15, 11:45 am

Temporal Dynamics of the Crowding Mechanism

Susana Chung¹(s.chung@berkeley.edu), Saumil Patel²; ¹University of California, Berkeley, ²University of Texas Medical School at Houston

Crowding refers to the difficulty in identifying an object when it is in close proximity with neighboring objects (the flankers). In this study, we examined the temporal properties of the flankers in relation to the target that render the flankers most effective in causing crowding. Stimuli were randomly drawn from the 26 lowercase letters. On each trial, a target letter was presented for 50 ms at 10° below fixation. The flankers, on the left and right of the target at a spatial separation (center-to-center) equivalent to 0.8x, 1.25x and 2x the x-height, were presented with a target-onset to flanker-onset asynchrony (TFOA) between -100 and 125 ms where positive values mean that the target preceded the flankers. Flankers were presented for 50 ms, 25 ms or 12.5 ms in separate blocks of trials. Observers' task was to identify the target letter. In general, the identification accuracy-vs.-TFOA plots resemble inverted U-shape functions. The dip of the function, representing the magnitude of crowding, was largest for 50-ms flanker duration and at the 0.8x target-flanker spatial separation, and became smaller for shorter flanker durations or larger spatial separations. Averaged across observers, maximal crowding occurred at a TFOA ~20 ms at 0.8x target-flanker spatial separation, shifted to ~50 ms at 2x separation, and did not depend on flanker duration. At any given spatial separation, the right limbs of the accuracy-vs.-TFOA plots for different flanker durations followed the same function; while the left limbs also became a single function if plotted with the stimulus offset asynchrony as the independent variable. These results constrain the temporal dynamics, particularly the integration time-constants, in the neural circuitry mediating crowding. Our results also provide evidence that maximal crowding does not require the target and flankers to be presented simultaneously; conversely, simultaneous presentation of target and flankers underestimates the crowding effect.

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22.16, 12:00 pm

Extraction of semantic information from unidentifiable, crowded words

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When targets are presented in the visual periphery with nearby flankers they may be crowded to the extent that they are unidentifiable. To what extent is the crowded target processed in the brain? A central question in crowding research is the nature of the processing for crowded information as the answer to this question will reveal where and how this visual limit is imposed. Here we examined whether semantic information can be extracted in the crowded situation using a primed lexical decision task with Chinese characters as stimuli. The prime and the target were semantically related or unrelated, and the prime was presented in isolation or with flankers. Manipulation checks on the effectiveness of crowding were conducted to allow the adoption of stringent criteria on a subject-by-subject basis for analyzing the semantic priming effect: Only the trials in which the prime was identifiable when presented alone and not identifiable when crowded were included. Results showed clearly that despite being unrecognizable and undistinguishable from matched non-characters, crowded Chinese characters still generated robust semantic priming in a subsequent lexical decision task. Indeed, the semantic priming effect on the lexical decision task was similar whether or not the primes were crowded and unrecognizable or not crowded and recognizable. These findings show that crowding does not prevent semantic activation suggesting that the locus of crowding

lie beyond the level at which semantic information is extracted, and further that semantic activation may pool information over a smaller spatial extent than that sampled for identification.

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22.17, 12:15 pm

Music-reading expertise alters visual spatial resolution for musical notation

Yetta Kwailing Wong¹(yetta.wong@gmail.com), Isabel Gauthier²; ¹Psychology Department, University of Hong Kong, ²Psychology Department, Vanderbilt University

Crowding occurs when the perception of a suprathreshold target is impaired by nearby distractors and it reflects a fundamental limitation on visual spatial resolution. Crowding limits music reading, since each note is crowded by adjacent notes and the five-line staff. We tested whether music reading experts have improved spatial resolution for musical notation. Twenty music reading experts and twenty novices were presented briefly with stimuli composed of a line and a dot in parafoveal region, where they judged whether the dot was on or off a line. In different blocks, these baseline stimuli were crowded by four additional staff lines or by two flanking dots, and we compared the Weber contrast threshold for 75% discrimination accuracy for the baseline and crowded conditions. Experts experienced a smaller crowding effect than novices for both crowding by staff lines or crowding by flanking notes. The magnitude of both types of crowding was predicted by individual music reading ability, measured by perceptual fluency with four-note sequences. In contrast to recent suggestion that crowding is independent of object category (Pelli & Tillmann, 2008), similar expertise effects were not found for non-musical stimuli (Landolt Cs): the reduced crowding effect in experts was specific to musical stimuli. The magnitude of both types of crowding was predicted by individual selectivity for notes for the N170 (120-200ms) component but also the C1 (40-60ms) component, measured with ERPs in a separate experiment in half of the participants. This suggests that the expertise effects in visual spatial resolution specific to musical notation may be related to changes as early as V1, consistent with a recent fMRI study showing expertise effects for musical notation in V1 (Wong & Gauthier, 2010) and with theories relating crowding to mechanisms in multiple visual areas (Fang & He, 2008; Levi, 2008; Millin, Arman & Tjan, 2010).

Acknowledgement: This work was supported by the JSMF and NSF (SBE-0542013) and the Vanderbilt Vision Research Center (P30-EY008126).

Perceptual learning: Transfer and specificity

Saturday, May 7, 10:45 - 12:30 pm

Talk Session, Royal Palm 4-5

Moderator: Michael Herzog

22.21, 10:45 am

Aging, perceptual learning, and perceptual efficiency in motion processing

Jeffrey D. Bower¹(jeffrey.bower@email.ucr.edu), George J. Andersen¹; ¹University of California, Riverside

In the present study we examined the use of perceptual learning to improve motion processing in older and younger individuals. Age-related differences in baseline perceptual inefficiencies and changes due to training were assessed, using the Perceptual Template Model (Lu & Doshier, 1998; 1999), for additive internal noise, tolerance to external noise, and internal multiplicative noise. In Experiments 1 and 2 we trained participants by manipulating contrast in noise embedded sine-wave gratings and Random Dot Cinematograms (RDCs). The results indicate that older observers have higher additive internal noise and lower tolerance to external noise compared to younger observers. The rate of perceptual learning in older observers was found to be similar to that of younger observers suggesting that plasticity for motion processing is well preserved in advancing age. Experiment 3 examined transfer of learning between sine-wave gratings and RDCs for both older and younger observers. The results indicate that transfer of learning occurred for both age groups. This suggests that older individuals maintain a sufficient degree of plasticity to allow generalization between sine-wave gratings and RDCs. In addition, training with RDCs was found

to produce greater perceptual learning than training with sine-wave gratings. The present studies provided important findings regarding changes in perceptual efficiency for motion perception in older adults and suggest that perceptual learning is an effective approach for recovering from age-related declines in visual processing.

22.22, 11:00 am

Non-retinotopic perceptual learning

Michael Herzog¹(michael.herzog@epfl.ch), Thomas Otto², Haluk Ögmen^{3,4}; ¹Laboratory of Psychophysics, Brain Mind Institute, EPFL, Switzerland, ²Laboratoire Psychologie de la Perception, Université Paris Descartes & CNRS, ³Center for Neuro-Engineering & Cognitive Science, University of Houston, ⁴Department of Electrical & Computer Engineering, University of Houston

Perceptual learning is usually specific for the encoded stimuli. For example, improvements in performance for a certain stimulus do not transfer if the stimulus is rotated by 90 degree or is presented at a different location. These findings are usually taken as evidence that orientation-specific and retinotopic synaptic changes underlie perceptual learning. To test this hypothesis, we used a recently developed non-retinotopic masking paradigm. An offset vernier was followed by nine consecutive pairs of non-offset flanking lines arranged along a circular trajectory, giving rise to the percept of two diverging and turning motion streams. Critically, the vernier itself was invisible but its offset was perceived at the last line of the stream, which had a different orientation and location than the vernier. For 4,000 training trials, sixteen observers attended to one motion stream and indicated the perceived offset direction (left vs. right). Performance improved significantly. In addition, we measured performance for various other stimulus configurations before and after training. Our results show that the improvement in performance is specific for the orientation and location of the perceived offset of the last line of the attended motion stream but not for the actual orientation and location of the invisible vernier. Hence, orientation-specific, retinotopic synaptic changes cannot explain our results. We propose instead that perceptual learning involves changes in non-retinotopic, attentional readout processes.

Acknowledgement: Swiss National Science Foundation

22.23, 11:15 am

Aging and Perceptual Learning in Orientation Discrimination

Denton J. DeLoss¹(ddelo001@student.ucr.edu), George J. Andersen¹; ¹Department of Psychology, University of California, Riverside

Previous research has shown aging causes decrements in orientation discrimination (Betts, Sekuler & Bennett, 2007). Perceptual learning (PL) training may be a possible intervention to counteract these declines. One primary concern in PL is that of specificity and transfer. PL studies have shown transfer with contrast and orientation across different locations in the visual field (Xiao et. al., 2008). The current study examined the transfer of PL training of orientation in younger (mean age 21.3, range 19-26) and older individuals (mean age 72.3, range 69-76). Eight younger and eight older subjects were given 4 days of testing and 3 days of PL training. A two interval forced choice procedure was used with two sequentially presented displays. On each trial subjects were presented with a centrally located Gabor patch oriented 40 degrees clockwise or counterclockwise off vertical (the standard) followed by a patch tilted clockwise or counterclockwise off the standard. Subjects were required to indicate whether the second display was tilted clockwise or counterclockwise off the standard. Participants were tested using a no noise condition and with 4 other levels of 2-dimensional Gaussian noise. Thresholds were determined using two interleaving staircase functions for their trained and untrained standards tested on separate days. During days 3, 4 and 5, participants were trained based on their previous performance in a no noise condition and a medium noise condition on their trained standard. Days 1, 2, 6 and 7 used the same procedure to assess orientation discrimination thresholds. Results indicate that PL training resulted in internal additive noise reduction and external noise exclusion, with older participants showing greater learning than younger participants. The improved performance in older participants was found to transfer to the untrained orientation. The importance of these findings to specificity, aging and the mechanisms of PL will be discussed.

Acknowledgement: Research supported by NIH EY0018334 and AG031941.

22.24, 11:30 am

What is learned in perceptual learning of the classical texture discrimination task?Rui Wang¹(heartygrass@gmail.com), Lin-Juan Cong¹, Cong Yu¹; ¹State Key Laboratory of Cognitive Neuroscience and Learning, Beijing Normal University, Beijing, China

The classic texture discrimination task (TDT) (Karni & Sagi, 1991) is used in numerous psychophysical and brain imaging studies on perceptual learning. An observer reports the global orientation (H/V) of a 3-oblique-bar array imbedded in a background of horizontal or vertical bars, which was flashed briefly and masked by a field of randomly oriented V's at various SOAs. Practice shortens the SOA threshold, but the learning is reportedly specific to the trained location and background orientation. Here we show that a majority of TDT learning is relevant to temporal resolution, not texture discrimination. Observers first learned (7-8 1.5-hr daily sessions) to discriminate the orientation of a letter "C" (flipped/no-flipped) on a clear screen which was flashed (13-ms) at the same location of the 3-bar target in a TDT task and then masked by a field of circles. This task only shared temporal and location properties with TDT. They then practiced TDT (4-5 sessions). The TDT improvement after initial "C" orientation learning accounted for >80% the overall TDT learning, and later TDT training accounted for the remaining <20% learning. Jittering the stimulus onset after training did not change the performance, indicating that what is improved is not the timing, but temporal resolution. In addition, TDT learning was found to be specific to the trained location in new observers, but further Vernier training in the diagonal quadrant (200_msec on a clear screen) enabled significant transfer of TDT learning, consistent with our previous double-training results (Xiao et al., 2008). Moreover, temporal learning as revealed by a similar "C" orientation task accounted for about half the learning of the famous feature detection task (Ahissar & Hochstein, 1997). These results suggest that temporal learning accounts for most TDT learning, and that the location specificity cannot be used to support a V1 site of TDT learning.

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22.25, 11:45 am

The specificity of perceptual learning of pop-out detection depends on the difficulty during post-test rather than trainingJordan Meyer¹(meyer.676@osu.edu), Alexander Petrov¹; ¹Psychology Dept., Ohio State University

The influential Reverse Hierarchy Theory (RHT, Ahissar & Hochstein, 1997, 2004) of perceptual learning posits that task difficulty determines the plasticity site during training, which in turn determines the amount of transfer to new stimuli on subsequent tests. RHT was formulated on the basis of pop-out detection experiments in which some observers trained and tested with easy stimuli ("EzEz") and other observers trained and tested with difficult stimuli ("DfDf"). This experimental design confounds the training and test conditions. Recent studies using full factorial designs suggested that the transfer of perceptual learning depended on the test and not on training in orientation discrimination (Jeter et al., 2009) and motion-direction discrimination (Petrov, 2009). Our present goal is to test whether this result holds for Ahissar & Hochstein's (1997) pop-out detection task. Method: The stimuli were 7x7 arrays of uniformly oriented lines. Half of the arrays contained a pop-out target whose orientation differed by 22 degrees from the background. Difficulty was manipulated via the target position uncertainty: 2 vs. 36 possible positions. After 4 training sessions (1400 trials each), the target and background orientations were swapped for 3 test sessions. Nineteen observers were assigned to 4 groups: EzEz, EzDf, DfEz, and DfDf. The threshold stimulus-to-mask onset asynchrony (SOA) was tracked using Ahissar & Hochstein's (1997) original adaptive procedure. Results: Thresholds decreased significantly with training in all groups. The learning effect transferred more in the EzEz than in the DfDf group, replicating the classic RHT pattern. However, no statistically significant differences were found at test between EzEz and DfEz or between EzDf and DfDf groups. Conclusion: The amount of transfer seems to depend on the difficulty during test and not during training for a variety of tasks, including the pop-out detection task. This challenges a key assumption of the Reverse Hierarchy Theory.

22.26, 12:00 pm

Perceptual learning transfers to untrained retinal locations after double training: A piggyback effectJun-Yun Zhang¹(zhangjy1982@gmail.com), Rui Wang¹, Stanley Klein², Dennis Levi², Cong Yu¹; ¹Institute of Cognitive Neuroscience and Learning, Beijing Normal University, ²School of Optometry, University of California, Berkeley

Perceptual learning can transfer to a new retinal location if additional training with an irrelevant task primes the new location ("double-training", Xiao et al., 2008), suggesting perceptual learning a more general process occurring in non-retinotopic high brain areas. However, learning is most useful if it can transfer to other untrained locations after double-training.

We measured the transfer of Vernier learning, which is very location specific, to untrained locations after double-training. (1) Two orthogonal Vernier stimuli were trained at separate visual quadrants. After training learning transferred to other untrained quadrants. (2) Vernier and a new task were trained at diagonal quadrants, respectively. Vernier learning always transferred to the diagonal quadrant. However, whether it also transferred to other untrained quadrants depended on the location specificity of the new learning task. The location-non-specific motion direction or orientation learning can piggyback Vernier learning to other locations at the same or different eccentricities, but location-specific contrast learning cannot. (3) Similar trends were observed when double-training was performed at the same location. Two orthogonal Vernier training showed no transfer of learning to other locations. However, Vernier learning did transfer to other locations with motion direction/orientation training.

We proposed that location specificity results from the learned high-level decision failing to functionally connect to the new inputs representing untrained locations. Double-training reactivates the new inputs to establish the functional connections to enable learning transfer. The current study shows that the brain may have learned to discount the location information and make the learning solely feature-based when a same task is trained at two locations. Moreover, for motion/orientation learning the learned decision unit may always connect to other locations that are constantly primed by motion/orientation stimuli. Vernier learning, once becoming contingent with these tasks, can be piggybacked to other locations through these tasks' active network.

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22.27, 12:15 pm

Training Older Adults to Improve Their Contrast Sensitivity: A Possible or Impossible Task?Mikki Phan¹(mhphan@wichita.edu), Rui Ni¹; ¹Department of Psychology, Wichita State University

Contrast sensitivity (CS) refers to the visual ability to detect small luminance differences between objects and the background. Age-related decrement in CS is associated with increased accident risk for older drivers. A number of perceptual learning studies have demonstrated improved CS through training for young adults. However, there is no research that has examined the possibility of improving older adults' CS. In this study, fourteen older adults (M = 77.86, SD = 9.41) were trained with contrast-related tasks for three days in a darkened room. Subjects were assigned into two training groups, each of which practiced either a contrast discrimination task (CSD) or a Gabor orientation discrimination task (GOD). In each training group, about half participants received training under high luminance condition (50 cd/m²) while the other half were trained under low luminance condition (3 cd/m²). Each participant was strictly trained monocularly in one of the standard orientation (45o or 135o). Pre-training and post-training thresholds were measured for each observer in each eye (except one observer), and under each luminance condition for each of the four different tasks (contrast detection task, contrast discrimination task, Gabor orientation discrimination task, and line orientation discrimination task). After the training, significant improvements were shown for the trained task for six out of eight observers in GOD training group and three out of the six observers in CSD training group. More importantly, transferred learning effects were found across untrained conditions, e.g. eyes, luminance levels, and most tasks. Interestingly, for observers in GOD group the learning did not transfer to the untrained CSD task and for CSD group the learning did not transfer to the untrained line orientation discrimination task. Overall,

the present study provides more evidence in support of neural plasticity in the aged brains. For older adults, contrast-related learning is more display-dependent than task-dependent.

Acknowledgement: WSU RIA Gridley Hoover Project

Saturday Morning Posters

Eye movements: Saccades and fixations

Saturday, May 7, 8:15 am - 12:15 pm
 Royal Palm 6-8, Poster Boards 301 - 320

23.301 Interaction between Sensory- and Goal-related Neuronal Signals on Saccade Trajectories in the Monkey

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Saccade trajectories are dynamic and may reflect the interaction between sensory- and goal-driven processes. In humans, saccades often deviate towards visually salient distractors, but saccades have also been shown to deviate away from spatially predictable distractors (Van der Stigchel & Theeuwes, 2006; Ludwig & Gilchrist, 2004). This has been attributed to spatially-local excitation versus inhibition at some neural site representing the distractor. We explored the relationship between saccade deviation and neuronal activity in the superior colliculus (SC), a crucial substrate for the integration of sensory- and goal-related signals for the production of saccades. Monkeys were trained to make a simple step-saccade to a peripheral target stimulus, and on a portion of the trials a salient distractor appeared at a nearby spatially predictable location (i.e., the same location on every trial). If the distractor appeared simultaneous with the target, correctly directed saccades (those whose end point was closest to the target) often deviated towards the distractor, but when the distractor appeared shortly before the target at various onset asynchronies (50-400ms), saccades began to systematically deviate away from the distractor. We divided the trials based on the degree to which the trajectories deviated away from the distractor and found that greater deviation away was associated with reduced activity at the distractor-related site in the SC beginning approximately 30ms prior to saccade onset. Conversely, we divided the trials based on the level of neuronal activity at the distractor-related site (from -30ms to saccade onset) and found significantly greater deviation away when activity was lowest. This is consistent with the idea that spatially-local excitation versus inhibition at the distractor-related SC site causes saccades to deviate towards versus away from salient distractors. Results are discussed in terms of SC lateral interactions and inhibitory nigrotectal projections (Jiang et al., 2003).

Acknowledgement: HFSP and CIHR

23.302 Investigating the role of intra-collicular excitatory connections in the generation of vertical saccades: A Human behavioural study.

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In neural models of saccade generation, lateral interactions between neurons in the topographic motor map of the Superior Colliculus play a major role in determining saccade metrics. By reshaping the activity profile that initially arises from visual stimulation, short-distance excitatory and long-distance inhibitory interactions favor the emergence of a main peak of activity, which determines in turn where the eyes move. Thus, when two spatially-proximal stimuli are displayed simultaneously in the same hemifield, the eyes land at an intermediate location between the two stimuli (i.e. the Global Effect) because short-distance excitations resume the two initially active peaks into one intermediate peak. Recently, we provided Human behavioural evidence for this assumption; we showed that the global effect cancels out when the spatial separation between two stimuli presented on the horizontal meridian exceeds a threshold distance of about 1mm of collicular surface, as previously suggested by electrophysiological investigations in the monkey [Casteau & Vitu 2009]. Here, we investigated whether this 1-millimeter threshold distance generalizes to stimuli presented on the vertical axis. A singleton peripheral target was presented on the vertical meridian either in isolation, or simultaneously with a less eccentric distractor displayed also on the vertical meridian. Both the eccentricity of the distractor (0°, 2 and 4°) and the angular separation between distractor and target (1° to 7°) were manipulated. In the target-alone condition, vertical

saccades were relatively accurate. In the distractor condition, saccade accuracy was virtually the same, meaning that there was almost no trace of a global effect. The eyes were rarely deviated towards the distractor, and this was mainly when the separation between the stimuli was extremely small. A way to reconcile these findings with the lateral-interaction hypothesis is to assume that short-distance excitatory connections within the motor maps are not oriented along the representation of the vertical meridian
 Acknowledgement: French-German ANR-DFG grant (#ANR-07-FRAL-014).

23.303 Oculomotor integration in patients with a pulvinar lesion

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The pulvinar nucleus of the thalamus, with its connections to visual areas and to frontal and parietal oculomotor cortex, might serve as a nexus for integrating cortical control of voluntary eye movements with reflexive eye movements generated by the superior colliculus. To investigate this hypothesis, we tested five patients with a unilateral lesion of the pulvinar on the oculomotor capture paradigm. In this task, participants have to ignore a distractor item and make a saccade to a target in a visual search display. Results showed that the interference of the distractor was stronger when it was presented contralateral to their lesion compared to when it was presented in the ipsilesional visual field. These findings were confirmed by an additional single case experiment in which we measured saccade trajectory deviations as evoked by a single distractor. These results show that the pulvinar is involved in the successful influence of higher-order signals (like our goals and intentions) on the guidance of our eye movements.

23.304 Distinctive Features of Saccadic Intrusions and Microsaccades in Progressive Supranuclear Palsy

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The eyes do not stay perfectly still during attempted fixation; fixational eye movements and saccadic intrusions (SIs) continuously change the position of gaze. The most common type of SI, square-wave jerk (SWJ), consists of pairs of horizontal saccades: the first saccade moves the eye away from the fixation target and, after a short interval, the second saccade brings it back towards the target. SWJs are prevalent in certain neurological disorders, including progressive supranuclear palsy (PSP). Here we developed an objective method to identify SWJs. We confirmed that SWJs are more frequent, larger and more markedly horizontal in PSP patients than in healthy human subjects. We also discovered that the loss of a vertical component in fixational saccades and SWJs is the eye movement feature that best distinguishes PSP patients from controls. We moreover found that in PSP patients and controls, the larger the saccade the more likely it is part of a SWJ. Further, all saccades produced by PSP patients had equivalent properties whether they were part of a SWJ or not, suggesting that normal fixational saccades (microsaccades) are rare in PSP. We propose that fixational saccades and SIs are generated by the same neural circuit, and that, both in PSP patients and in healthy subjects, SWJs result from a coupling mechanism that generates a second corrective saccade shortly after a large fixation saccade. Due to brainstem and/or cerebellum impairment, fixational saccades in PSP are abnormally large, and thus more likely to trigger a second corrective saccade, giving rise to SWJs.

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23.305 Topography of saccadic eye movement representations in human superior colliculus

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Purpose: Neural microstimulation experiments in the superior colliculus (SC) of non-human primates have demonstrated a topographically organized representation of saccadic eye movements by neurons within the intermediate layers of the SC (Robinson, Vision Research, 12, 1972). A recent study using fMRI showed lateralization of saccade related activity in the human SC (Krebs et al, PLOS One, 5, 2010). Here, we examine the topographic representation of saccades in human SC. **Methods:** We used saccade targets (high-contrast 0.5° dots) that could appear anywhere within a wedge-shaped region (eccentricity 4–10°, azimuthal width 12°) that slowly rotated (48-s period) around the fixation mark. Subjects made alternating centrifugal and centripetal saccades to the eccentric and fixation targets respectively while performing a shape discrimination task (square or triangle) within each target with each trial lasting 0.8 seconds. High-resolution fMRI (1.2 mm voxels, 3-shot spiral, TE = 40 ms) was acquired (3 s/volume) in 8 slices that covered the whole of the SC. **Results:** We observed that the polar angle of the saccade directions was represented upon both left and right SC, with the upper-lower visual field mapped in a roughly medio-lateral direction, within a narrow band along the rostrocaudal direction. Preliminary results suggest that the maps agree well with previous measurements the representation of visual stimulation in the superficial layers of human SC (Katyal et al., J Neurophysiol, in press). Depth profiles of the activity suggest that the activity peaks slightly below the superficial surface of the SC. **Conclusions:** High-resolution fMRI can resolve retinotopic maps of saccadic eye movements in the intermediate layers of human SC. The observed topography is similar to that observed in non-human primates.

23.306 Deciphering the relationship between perceptual and motor variability

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The time that elapses between stimulus onset and the initiation of a saccadic eye movement is longer and more variable than can be explained by neural transmission times and synaptic delays (Carpenter, 1981, in: Eye Movements: Cognition & Visual Perception, Earlbaum). In fact, the correlation between response time and stimulus strength is surprisingly weak ($r < 0.5$), suggesting a relatively large source of internal (neural) noise. In theory, noise underlying response-time variability could arise anywhere in sensorimotor pathways, at any stage from early sensory processing to motor output commands. These loci can be distinguished empirically; if early (shared) visual noise dominates then saccadic response time will correlate with perceived stimulus magnitude whereas if late oculomotor (unshared) noise dominates there should be no such correlation. **Methods.** Five participants ran a two-stage task in which they first performed a 2AFC saccadic brightness discrimination task (to determine response rate or the inverse of response time) and then a second, method of adjustment, brightness matching task between the remembered chosen stimulus and a variable test stimulus (to determine perceived brightness). **Results.** We plotted both perceived brightness and response rate (normalized and pooled across participants) as a function of signal strength and used a linear regression model to isolate, on a trial-by-trial basis, the residual effects of internal (neural) noise on the perceptual and motor responses from any external (stimulus brightness) driven variability, including that caused by the stochastic nature of our stimuli (Liston and Stone, 2008, JNS 28:13866-13875). The two internal noise estimates were significantly positively correlated (Pearson's R , $p < 0.01$). **Conclusion.** The correlation between the neural noise effects on saccadic response time and perceived brightness is consistent with shared early visual noise jittering brightness perception and saccades in parallel as has been previously observed for motion perception and smooth pursuit (Stone and Krauzlis, JOV 3:725-736, 2003).

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23.307 The antisaccade task: dissociating stimulus and response influences online saccade control

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Antisaccades require the suppression of a stimulus-driven response (i.e., response suppression) and the computation of a movement plan mirror-symmetrical to the location of a target (i.e., vector inversion). The goal of the present study was to determine whether response suppression, vector inversion, or both, contribute to previously reported differences in the online control of pro- and antisaccades (Heath et al. 2010: Exp Brain Res). Pro- and antisaccades were completed in separate blocks (i.e., blocked schedule) and a block wherein the spatial relation between stimulus and response was provided at response cuing (i.e., random schedule). Notably, the random schedule provides a relative means for equating response suppression across pro- and antisaccades. To examine online trajectory amendments, we computed the proportion of variance (R2 values) explained by the spatial location of the eye at early, middle and late stages of saccade trajectories relative to the saccade's ultimate movement endpoint. The basis for this analysis is that between-task differences in R2 values reflect differences in trajectory control: small R2 values are taken as evidence of an online mode of control whereas larger R2 values are taken to reflect a trajectory that unfolds with reduced online and error-nullifying amendments. Prosaccade reaction times were faster than antisaccades; however, this difference was reduced when tasks were equated for response suppression (i.e., the random schedule). Additionally, antisaccades yielded larger R2 values than prosaccades from early to late stages of saccade trajectories and this finding was consistent across blocked and random schedules. In other words, the spatial location of the eye during antisaccade trajectories was more predictive of the response's endpoint. Thus, we propose that the intentional nature of vector inversion disrupts the normally online control of saccades and results in a cognitive mode of control that is not optimized for trajectory amendments.

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23.308 Distinct Response Latencies do not Influence Pro- and Antisaccade Trajectories

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Previous work by our group has shown that antisaccades exhibit reduced online corrections relative to prosaccades (Heath et al. 2010: Exp Brain Res). In that previous work, the onset of a target stimulus served as the movement imperative cue, and as a result, prosaccade reaction times (RT) were reliably faster than antisaccades. However, it is possible that the reported difference in online corrections may relate to the temporal limitations of the constituent planning processes underlying the antisaccade task (i.e., response suppression and vector inversion). To address this issue, the present study had participants complete stimulus-driven and memory-guided pro- and antisaccades. Notably, the memory-guided condition was employed to equate pro- and antisaccade RTs. To index online control, we computed the proportion of variance (R2 values) explained the spatial location of the eye at normalized deciles of movement time relative to the response's ultimate movement endpoint. The basis for this analysis is that smaller R2 values at any point in the trajectory indicate that the position of the eye does not reliably predict the response's ultimate endpoint and is therefore indicative of online trajectory corrections. In turn, larger R2 values are interpreted to reflect fewer online corrections. RTs for stimulus-driven prosaccades were faster than matched condition antisaccades; however, this advantage was nullified in the memory-guided task. Moreover, antisaccade R2 values from the early to late stages of the response were larger than their prosaccades counterparts and this finding was consistent across stimulus-driven and memory-guided conditions. Thus, between-task differences in online control cannot be attributed to premovement costs in response planning; rather, evidence indicates that the top-down nature of the antisaccade task engenders a presetting of the oculomotor system and renders a mode of control that is not optimized to support online corrections.

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23.309 Reliability and sensitivity of anti saccade in a block versus mixed paradigm

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To perform an anti-saccade, participants need to inhibit the saccade in the direction of a peripheral target, to program and execute a saccade toward the target mirror position. The variables of interest are the percentage of saccade in the wrong direction (errors) and the antisaccade reaction time. As review by Everling and Fischer (1998), a large number of clinical studies have been conducted with anti-saccade tasks. The task is a reliable and a sensitive measure often used to dissociate the different components of saccade preparation and execution. Therefore, anti-saccades are proposed as a diagnostic tool to investigate different pathologies like schizophrenia, Parkinson or mood disorder. This study proposed to investigate: (1) the reliability of anti-saccade tasks (2) the effect of repeating several sessions of anti-saccades and (3) the interaction with other oculomotor task. In fact different studies dealt with contradictory results (for a review see Smyrnis, 2008). We asked 32 participants to perform anti-saccades. For 16 participants, the anti-saccades were repeated in all trials (block paradigm). For the other participants the anti-saccades were interleaved with prosaccades and nogo trials (mixed paradigm). Each participant repeated 3 times the experiment (sessions 1, 2 and 3) with one week between. We found that anti-saccade tasks in both paradigms are reliable (Intra-class correlation and Pearson correlation coefficients). We found a significant effect of the session on saccadic reaction times and saccade errors for both paradigms. This effect is mainly due to a large decrease of reaction times and errors between the two first sessions. The decrease is not significant between the two last sessions. To conclude, when asking participants to perform anti-saccades in mixed or block paradigms measures are reliable. However, one should be conscious that there is a possible learning effect that could interact with any clinical prescription.

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23.310 Word Processing Speed in Peripheral Vision

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According to Kirchner and Thorpe (2006), it takes less than 120 ms to detect the presence of an animal in peripheral vision. Here we investigated whether the same applies to a very different kind of visual object: printed words. Using their forced-choice saccade paradigm, we measured the time to initiate a saccade to target stimuli presented in peripheral vision (6 ° left or right of a central fixation mark). Targets were pictures of animals in one block and 5-letter words in another block. Targets were accompanied by distractor stimuli in the contra-lateral visual field, which were visual scenes without animals for animal targets, and random strings of consonants for word targets. To limit differences between words and images and compensate for the visual acuity decrease in peripheral vision, we used large words (about 1.7° per letter). Targets were also presented without contra-lateral stimuli in a control condition. Although saccade latencies did not differ across words and animals in the control condition, we found that animal detection was faster and more accurate than word detection. The estimated fastest latencies of saccades to the target were 140 ms and 200 ms respectively for animal and word targets. The results for animal targets replicate those reported by Kirchner and Thorpe (2006). The timing found for word targets shows that word identification processes require more time. Within 200ms, combinations of letters can be processed and can direct eye movements to the target words even if word identification is not complete. This is in line with estimated time-course of visual word recognition derived from ERP studies of foveal word recognition (Grainger and Holcomb, 2009). Our findings raise the possibility that words are processed by mechanisms that have adapted to the specific constraints imposed by printed words compared with other types of visual object.

Acknowledgement: European Research Council

23.311 Saccades to color: an ultra-fast controllable mechanism to low-level features

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Certain key stimuli such as animals or human faces can trigger very fast saccades from as early as 100 or 120ms after image onset (Crouzet et al, J Vis, 2010). Can such fast saccades be seen to other more conventional visual stimuli? Here we directly compared the speed and accuracy of saccades to targets defined by either color or orientation. We presented four circular grating patches at equal distances from fixation for 400 ms. There were four different colors (red, green, yellow and blue), and four orientations (vertical, horizontal, left and right oblique) combined randomly. For each of 8 blocks of trials, participants were instructed to target either a particular color, or a particular orientation. Surprisingly, with targets defined by orientation, performance was essentially at chance. In contrast, when the target was a particular color, performance was very good, and even very fast saccades initiated at latencies as short as 120-130 ms were biased towards the target color. We suggest that this major difference between color and orientation could reflect whether top-down task-related modulation can influence the initial part of the neuronal response. In the case of orientation, although clearly millions of neurons in V1 will code orientation explicitly, if their initial responses are unmodulated by the task, all the orientations would initially be equivalent. In contrast, if top-down effects can modulate the initial responses of color-selective neurons early on in the visual pathways, this could increase effective saliency of the target color and allow fast saccades to be triggered. Intriguingly, while performance was particularly good for red, yellow and blue targets, accuracy for green targets was about 30% lower and reliable saccades were not seen until 30-40 ms later. Further experiments are currently being performed to try and determine the reasons for this poorer performance for green.

23.312 Eye And Hand Coordination: Comparing Effects of Age on Performance

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Eye and hand coordination is essential for everyday activities. Saccadic eye movements play an important role in ensuring that objects of interest are aligned with the foveal region of the retina. Information of eye position can then be used to produce a hand response to the desired location. Developmental abnormalities in the control of saccades may hinder the coupling between eye and hand movements (Wilmot et al. 2006). This study aims to provide better understanding of disorders by assessing oculomotor control throughout normal development. Recent studies have reported immaturities in children's ability to inhibit saccades and maintain fixation (Luna et al. 2004); however, age ranges vary across studies and measuring techniques lack sensitivity compared to modern eye-tracking technology. We investigated age-related differences in the generation of reflexive and voluntary saccades and hand responses during pre-cued and non pre-cued visually guided tasks. Saccades and hand responses were measured from 20 adults (20-26 yrs) and 7 children (9-12 yrs). Participants performed the tasks using their eyes only, hand only and eyes + hand together, to investigate the use of visual information during visuomotor tasks. During the pre-cued condition, children exhibited longer saccade onsets compared to adults; however, saccade onsets significantly decreased during the non pre-cued condition and were similar to adults'. Children's hand responses were also slower during pre-cued conditions indicating tight coupling of the eye and hand. Hand movement times also showed that adults used advance information of the target location more efficiently than children. Eye and hand absolute errors were similar between groups; however children exhibited greater variability. Pre-cued results showed developmental costs in attention disengagement, but not in the inhibition of intrusive saccades. These findings provide insights into the development of eye and hand coordination and maturation of cognitive control and have significant implications in understanding developmental coordination disorders.

23.313 Development of Coordinated Eye and Head Movements during Gaze Shifts

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Gaze shifts of primates are characterized by coordinated eye and head movements. Although much effort has been put forth to reveal the neural substrate underlying the gaze shift control system or to find the optimality principle behind its dynamics, it remains unclear how such a control scheme develops in primates. In this theoretical study, we start by assuming a simple cost function and a plausible neural learning model. The cost function depends on the instantaneous visual error signal integrated over time, plus a regularization term. We proceed by training the neural model with respect to the proposed cost function using learning rules that are biologically plausible. While these learning mechanisms adjust the connection strengths of the neural model, we manipulate the free parameters of the model to match its behavior to experimental observations. Using a set of such parameters for head-restrained (HR) and another for head-free (HF) gaze shift conditions, our model is able to reproduce many of the gaze shift characteristics observed in experiments. These characteristics include the saccadic main sequence and the bell-shaped velocity profiles in HR, and the relative contribution of eye and head to the gaze shift as well as its dependence on initial eye position in HF conditions. Furthermore, our model reproduces the early fixation phase of the eyes in HR and the so-called vestibulo-ocular reflex (VOR) phase in HF conditions. All of these results are gradually achieved through incremental learning, which implies that the visuomotor system may incorporate a similar kind of learning to constantly calibrate its control circuitry with respect to a cost function. The model can be generalized to other ballistic motor control tasks beyond gaze shifts by finding appropriate motor plant models and cost functions.

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23.314 Eye movements during and after automatization of a high-speed stacking task: From sensory-based to memory-based saccadic programming

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Humans move their eyes via saccades several times per second to informative locations of the environment while performing natural tasks. We investigated how saccades in such a task change during learning and automatization and whether eye movement patterns after extensive training are similar for visible and invisible objects. To that aim, we applied a bimanual, high-speed motor task requiring grasping, moving, rotating, and putting down objects. Eye movements were recorded during the training phase and also compared under visual illumination and in the dark after training. With increasing automatization of the task, the eye-hand leading time became smaller and fewer fixations were made, while fixation rates remained constant. The comparison between normal vision and darkness revealed lower fixation rates and longer fixation durations in the dark, while eye-hand coordination and scanpaths were very similar. Results indicate that a distinct saccadic pattern is learned and transferred to long-term memory during automatization. After the training period, sequences of saccades are retrieved from long-term memory. These preprogrammed saccades are executed even in the dark. Interestingly, scanpaths similarity between normal illumination and darkness conditions was not related to task performance. Possibly, saccadic eye movements have no function, when no visual feedback is available. However, the inhibition of automatized eye movements might have an additional cost. Deductively, results point to a shift from sensory-based to long-term memory based visual selection during learning and automatization.

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23.315 Effect of task and behavioral demands on saccadic targeting

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Saccades are typically hypometric, and this hypometria generally scales with target eccentricity. However, it is not clear how specific aspects of task demands influence the accuracy and precision of saccades. We investigated the effect of target direction, task demands at the target location and the type of saccade made (endogenous or exogenous) on the precision and accuracy of saccades.

We measured saccades for five normally sighted observers while completing two tasks. Targets were presented at 1 of 8 polar angles and the target eccentricity was blocked, ranging from 2-12°. Instead of a simple saccade task, observers were asked to make a saccade to: 1) discriminate the location of the gap in a Landolt C (4AFC) or 2) make a rapid point to a target. Additionally, we cued the saccade with either an endogenous or exogenous cue. Saccade endpoints are hypometric with respect to the target, and this error scales with target eccentricity, consistent with previous findings. Saccades are less precise in the radial direction than tangential. In conflict with Findlay (2008) we did not find an effect of exogenously versus endogenously cued saccades in the acuity task, suggesting that the targeting error is driven by the resolution of task-dependent visual information. However, there was a clear effect of task on saccade targeting. When reaching to a target, saccade endpoint errors showed the same patterning, but both accuracy and precision worsened as compared to the acuity task. For close targets (2 and 4°), more than one subject did not even make saccades on almost half of the trials. Saccade targeting error is affected by the visual resolution demands of the task. In the limiting case of an acuity task when an accurate saccade is most needed, it is irrelevant whether the saccade is made reflexively or intentionally.

Acknowledgement: NIH R01 EY018004-05 to LWR and Smith-Kettlewell Pilot Award

23.316 Absence of an extraretinal signal associated with ocular drift affects saccade accuracy

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During a saccade, a copy of the oculomotor command updates spatial representations and suppresses motion perception in order to yield perceptual stability. A similar need for a stabilization mechanism also exists during visual fixation, when microscopic eye movements incessantly shift the retinal image. In a recent study, we have shown that motion judgments can be predicted on the basis of retinal image motion irrespective of the amount of ocular drift (Poletti et al., J. Neurosci. 2010). These findings suggest that, unlike during saccades, visual stability during fixational drift relies on the motion of the stimulus on the retina rather than on an extraretinal signal. However, the possibility remains that an extraretinal drift signal which eludes awareness is available in the motor system. Discrepancies between action and perception have been previously reported in the literature. Here, we examined whether an extraretinal signal associated with ocular drift influences the execution of a later saccade. Human observers were asked to maintain fixation in complete darkness and saccade toward a briefly cued location. The saccade was executed after an auditory signal which came 2s after the display of the target cue. In this interval, drift moved the eye away from the position assumed at the time of display of the target cue. Across subjects, ocular drift was on average larger than 40'. If motor knowledge of this drift is available to the brain, saccadic amplitude and direction should be properly adjusted so that the saccade lands on the target. We show, instead, that saccades do not compensate for the preceding drifts, and that the distance between the target and the landing position increases with the amount of drift. These results show that the visual system does not use a motor signal proportional to drift to compensate for possible shifts in the location of gaze.

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23.317 Eye movements when viewing oriented noisy textures

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We redirect our eyes approximately 3 times per second to bring a new part of our environment on to our fovea. How a scanning path is planned, is still an unsolved matter. We questioned whether orientations, ubiquitously present in our environment, can be helpful guides in redirecting our point

of fixation. To this end, we studied saccades made in response to oriented Gabor patches that were embedded in circular patches (radius of 8°) of pink ($1/f$) noise. We varied the saliency of randomly oriented Gabors, that either had a high or a low spatial frequency (2 & 16 cycl/ $^\circ$), by changing their contrast. Five subjects were instructed to fixate the center of the screen and then were free to make eye movements during the $2s$ presentation of the stimuli. We asked subjects to report the perceived stimulus orientation after it had disappeared, by rotating a black line using the mouse. Eye movements were measured using the head-mounted EyeLink II system. We analyzed saccade direction of both small ($\leq 1^\circ$) and large ($> 1^\circ$, $< 10^\circ$) saccades made during stimulus presentation. The data showed that in the lowest contrast conditions, the orientations were hard to distinguish (for only 2 subjects in these 2 conditions the perceptual response was significantly correct (Rayleigh test on corrected response)). The saccade directions were random, similar to search like behavior. In the other conditions, especially for the low spatial frequency Gabor, perceptual responses were almost always correct. For 3 out of 5 subjects, the saccadic responses were aligned with the orientation of the Gabor (significant Rayleigh test result), for saccades with an amplitude larger than 1° (and smaller than 10°). Our results show that orientation does have an effect on saccadic eye movements. Saccades, with amplitudes larger than 1° , are made predominantly along the orientation of these textures.

23.318 Predicting the responses of retinal ganglion cells during fixational eye movements

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The response characteristics of retinal ganglion cells are often studied in anesthetized animals with paralyzed eyes. Under natural conditions, however, the input to the retina is also modulated by the self-motion of the observer. Eye movements continually occur, even during visual fixation, when microscopic eye movements incessantly shift the retinal image and modulate visually-evoked responses in ganglion cells. It is, therefore, critical to understand how neuronal response properties determined in the absence of retinal image motion apply to natural viewing conditions. In this study, we describe an "equivalent filter" of retinal ganglion cells, a filter which incorporates the statistics of human fixational eye movements and the cell response characteristics measured with an immobile stimulus in order to estimate the response properties of ganglion cells under the normal instability of visual fixation. Traces of oculomotor activity recorded from human observers while maintaining fixation on a small marker were used to reconstruct the typical spatiotemporal input to the retina during natural fixation. This input signal was then processed by filter models of parvocellular (P) and magnocellular (M) cells designed on the basis of published data from neurophysiological experiments with anesthetized and paralyzed macaques. We show that neuronal sensitivity to time-varying inputs shifts towards higher spatial frequencies during fixational eye movements. That is, the peak sensitivity of the equivalent filter occurred at a spatial frequency which was more than twice that of the contrast sensitivity function measured in the neurophysiological experiments. This effect occurred for both P and M cells at all the considered visual eccentricities. Thus, contrast sensitivity functions measured in the absence of eye movements seriously underestimate neuronal sensitivity to high spatial frequencies under normal viewing conditions.

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23.319 Analysis of individual variability in fixational eye movements

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Our eyes are always in motion. Even when we attempt to keep the gaze steady on an object of interest, microscopic eye movements, which include microsaccades and drifts, continually shift the stimulus on the retina. It has long been known that fixational eye movements differ significantly among observers. However, a systematic characterization of individual variability in the pattern of microscopic eye movements has not been reported in the

literature. In this study, we used a DPI eye tracker, a high-resolution device which enables observation of both microsaccades and drifts, to study how the two types of fixational eye movements contribute to maintain fixation in human observers. Subjects ($N=14$) were asked to maintain prolonged fixation in various conditions, including the presence/absence of a fixation cue (a $5'$ dot) and the presence/absence of a textured background (a natural image). Fixation was most accurate with a fixation cue, irrespective of whether the background was textured or uniform. In this condition, the area containing the line of sight with 0.75 probability was on average 464 arcmin² and varied across observers by more than a factor of 10, ranging from less than 100 to more than 1000 arcmin². Among all the examined oculomotor parameters the best predictor of fixation was the speed of ocular drift; subjects with lower drift speed systematically exhibited more accurate fixation. Without a fixation cue, the 0.75 probability area of gaze increased by a factor of 2 to 4 depending on whether or not a textured background was present. In this condition, each observer maintained their own speed of drift, but drift covered a much larger area. Microsaccades were less frequent but substantially increased in amplitude and heavily contributed to the instability of fixation.

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23.320 Non-uniform vision within the fovea might explain microsaccade production

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We recently reported that, during execution of a visuomotor task, microsaccades redirect the preferred retinal location between stimuli at distances smaller than the size of the fovea (Ko et al., Nature Neurosci. 2010). A possible explanation for this finding is that vision is not uniform across the fovea, and microsaccades are used to relocate the stimulus on the optimal retinal region for the given task. Although visual acuity is commonly assumed to remain constant within the fovea, anatomical examinations of the foveal region have in fact revealed changes in neuronal characteristics. Here we studied visual discrimination with stimuli located at different eccentricities within the fovea. In a forced-choice discrimination task, subjects reported if two successively presented gratings had the same or opposite orientation. Gratings were viewed through a $5 \times 20'$ rectangular aperture, which was centered at $4'$, $9'$ or $14'$ from the preferred retinal location and displayed first to its left and then to its right. Stimuli were either observed normally or under retinal stabilization. In this latter condition, retinal image motion was eliminated so that the stimulus remained at a fixed retinal eccentricity. Under retinal stabilization, discrimination performance at all eccentricities should be approximately equal if vision was homogeneous. In contrast, we found that discrimination percentages with stimuli at $9'$ and $14'$ were significantly lower than at $4'$. Percentages were instead comparable at all eccentricities in the normal condition, when eye movements normally moved the retinal stimulus. In this condition, microsaccades systematically relocated the gaze from one grating to the other significantly improving performance at $9'$ and $14'$. These results suggest that vision is not uniform across the fovea and that, in highly demanding task, the need exists for precisely relocating the stimulus within the foveal region.

Acknowledgement: Grant NIH R01 EY18363 and NSF BCS-0719849

Visual search: Eye movements

Saturday, May 7, 8:15 am - 12:15 pm
Royal Palm 6-8, Poster Boards 321 - 329

23.321 Guidance during Visual Search in Real-World Scenes: Scene Context vs. Object Content

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A number of past studies have shown that when searching for an object in a scene, eye movements are guided towards the target based on scene context by selecting the most relevant areas. Other studies have shown that fixations are directed to high spatial frequency information, corresponding to objects in the scene (van Diepen & Wampers, 1998). In a previous study, Castelhanò and Henderson (2007) showed that when no immediate visual information is available (via moving-window paradigm), scene context can dominate search strategies. In the present study, we examined whether search strategies are equally affected when information regarding the scene

context and placement of object content are immediately available and juxtaposed. Participants searched for a target using a gaze-contingent moving-window paradigm. The original search scene was shown foveally (inside the window), while the scene information was manipulated extra-foveally across four conditions: (1) Full Scene: search scene excluding the target; (2) Empty Scene: search scene with all objects removed; (3) Fractioned Scene: search scene with only a small number of objects; and (4) No Scene: a black screen control. Thus, the Empty Scene provided scene context information alone, while the Fractioned Scene provided additional information about object content that did not overlap with the target. While results showed search was best in the Full Scene condition and worst in the No Scene condition, we found across a number of eye movement measures that there was no difference between the Fractioned and Empty Scene searches. This pattern was seen in the latency to first target fixation, the number of fixations before the first target fixation and in reaction time. The picture that emerges seems to support previous studies indicating that scene context information may be more useful in guiding eye movements during search than object-based features.

23.322 Searching for target parts

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Real-world objects typically consist of multiple parts. When searching for a multi-part object, are all of its parts used, or just a select few? In experiment 1, participants were cued with one, three, or all four parts of a photorealistic teddy bear target, then searched for the whole target among three other images of whole teddy bears. We found that reaction times ($p < .001$), accuracy ($p < .001$), guidance (as measured by time to target fixation; $p < .05$), and verification time (as measured by time between target fixation and response; $p < .001$) all improved with the number of target parts added to the cue, suggesting that all of these parts were loaded into visual working memory and used to facilitate search. However, some parts were more useful than others. Guidance ($p < .05$) was best when the torso of the target bear was cued; accuracy ($p < .05$) and verification time ($p < .01$) were best when the bear's head was cued. In experiment 2, participants were cued with the whole bear, but now the search display depicted 4-part (whole bear), 3-part, or 1-part target and distractor bears. Accuracy ($p < .05$) and verification time ($p < .05$) were again best when the target's head appeared in the search display, but no benefit was found for search guidance ($p > .05$). We conclude that the head/face is preferentially weighted in the target representation when the target contains a head/face, in conjunction with other parts. However, when considered separately, the torsos of our targets allowed for the most effective guiding template, perhaps because they were more homogenous in texture and color. Our results suggest that search guidance increases with the number of target parts, but that all of these parts are not equally effective in guiding search.

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23.323 The odd human eye movements during oddity search are not suboptimal

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Studies have shown that when humans search for a known target, eye movements are often guided towards target features (e.g., Findlay, 1997) with occasional fixational compensations for inhomogeneous processing across the visual field (Najemnik & Giesler, 2005). In a different type of search (oddy search), targets and distractors are not known beforehand and observers have to determine whether an element in the display differs from others (distractors) along some feature. Previous research has shown that oddity search has different behavioral properties from target known search, such as different effects of set-size (Bravo & Nakayama, 1992; Schoonveld et al., 2007). Here, we measure human saccadic eye movements during an oddity search task and develop an optimal foveated oddity searcher, which fixates locations that maximize search accuracy, to evaluate human eye movement strategies. Observers performed a yes/no search task in which they were to determine whether one of the five potential target locations contained a singleton target. Stimuli consisted of Gabor patches at three orientations (5° left, vertical, 5° right) embedded in white noise at five locations around an imaginary circle (6° radius). For target present trials, the target was randomly selected from the three possible elements, while one of the remaining elements occupied the other four locations (distractors). For target absent trials, all five locations contained the same randomly selected

element. Participants viewed each stimulus for 700ms (allowing approximately three eye movements) before making a decision. Unlike typical strategies for target known search, observers adopted an eye movement strategy for the oddity search in which they systematically fixated three locations regardless of the stimulus configuration. Such strategy shows little guidance towards the target location. We find that the optimal foveated oddity searcher, like humans, seeks to survey as many of the potential target locations as possible and shows little target guidance.

23.324 Examining Eye Movements in Visual Search through Clusters of Objects in a Circular Array

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Objects tend to be clustered in the environment. This clustering could affect both search processes and the eye movements used to execute a search. In order to examine this possibility, participants in the current study were asked to search for a complete O in an array consisting of eight clusters of four Landolt Cs arranged in a ring. The similarity of the distractors to the target was manipulated systematically by varying the size of the gap in the Cs, but the gap size for all of the Cs in a cluster was the same. Consistent with many search studies, the response time data were consistent with a serial self-terminating process. More importantly, eye movement data supported the serial processing model because clusters were fixated serially (either clockwise or counterclockwise) on most trials and (b) fixation times on a cluster reflected processing time on that cluster and were unaffected by the gap size of either the prior or succeeding cluster. In other words, processing difficulty of a cluster had no effect on later fixations, nor did the processing difficulty of a cluster affect fixations before that cluster was fixated. Furthermore, the pattern of fixation times on a cluster was similar to the pattern of response times in a secondary task where a single cluster was presented at fixation. These data extend the findings of Williams and Pollatsek (2007) in which search was through a linear sequence of clusters, and indicate that a serial search pattern is not confined to reading-like arrays.

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23.325 Coarse-to-Fine Search Strategy when Searching in Clutter

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Over et al. (2007) reported that when participants are searching in complex displays, they use a coarse-to-fine search strategy in which, as search progresses, the duration of fixations increases and the distance between fixations decreases. In the current study we examined the extent to which participants employed a coarse-to-fine search strategy while searching for an elevation marker in aeronautical charts of varying amounts of visual clutter. Our previous work demonstrated that search time increased as the amount of clutter in the chart increased (Beck et al., 2010). Search may be faster in less cluttered charts because attention within each fixation can be spread over a larger region of the chart (evidenced by longer saccades) and/or because the information within the attended region of each fixation can be processed more quickly (evidenced by shorter fixation durations). Replicating previous research, we found that reaction time increased as chart clutter increased. Examination of eye movements during search revealed that participants were using a coarse-to-fine search strategy in charts of all levels of clutter; as search progressed, the duration of each fixation increased and the distance between two fixations decreased. However, this effect was weakest in the least cluttered charts. Interestingly, the amount of global clutter (i.e., average clutter of the entire chart) affected fixation durations more than the distance between fixations. When global clutter was low, fixation durations were shorter, but the distance between fixations was similar to that in more cluttered charts. This suggests that higher levels of global clutter increase the time needed to process information within a given region, but do not change the size of the region attended during the fixation. In conclusion, a coarse-to-fine search strategy was found for maps of all levels of clutter, and less cluttered maps did not lead to a broader focus of attention.

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23.326 **The effect of temporal distance on comparative visual search**

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The spatial distance between two simultaneously presented pictures determines comparative visual search (CVS) behavior. With increasing distance, humans conduct fewer gaze-shifts between two simultaneously presented pictures when searching for differences, suggesting a higher use of the visual short-term memory (VSTM). Previous research examined search behavior with pictures presented next to each other thus not only varying spatial but also temporal distances as the gaze-shift duration increases with increasing distance between picture pairs. In this study we examined the contribution of pure temporal distances to the trade-off between the number of changes between pictures and VSTM use. We hypothesized that longer temporal distances between two alternating images leads to higher VSTM use. We further hypothesized a higher use of chunking strategies for participants with domain knowledge. Prior to the search task participants received either stimulus-related or -unrelated information thus manipulating domain knowledge. Participants had to search for differences between two pictures of a pendulum clock that were presented on one display one at a time. They could alternate between them by pressing a key. The change was delayed by 120 or 500ms. We measured the number of shifts between the pictures and recorded gaze behavior. Results showed a trade-off between the number of shifts between pictures and the temporal distance. This replicates effects known from CVS with pure temporal instead of both temporal and spatial distances. Further, participants with domain knowledge conducted a smaller number of shifts in both distance conditions suggesting a higher use of chunking strategies. Eye tracking data complement the findings. Participants who received domain knowledge showed a fewer number of fixations and smaller saccade amplitudes. This is in line with findings in eye tracking literature. In sum, there is an influence of domain knowledge on the replicated trade-off in a temporal CVS paradigm.

23.327 **Eye movement patterns underlying robustness against item motion in visual search**

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Hulleman (2010) found that item movement caused a decrease in search performance only for very difficult search tasks, whereas performance in easier tasks was not influenced by motion. Here, we investigate the relationship between eye movements and performance in search tasks of varying difficulty using static (0.0 deg/s) and moving (7.2 deg/s) items. The easy search task consisted of searching for a diagonal line amongst vertical lines, medium search was for a T amongst Ls and difficult search was for a square with a notch in the top left corner, amongst squares with a notch in one of the other corners. During present trials there was no effect of item speed on search performance for any difficulty level. During absent trials search performance was worse for moving items at all difficulty levels, perhaps the result of a more conservative stopping rule for moving items when the target is not found. Fixation durations, fixation counts and saccade amplitudes mainly depended on the level of difficulty rather than level of motion. However, there were some effects of speed, even for present trials. For moving items, at all difficulties, for both absent and present trials, there was a larger distance between the start point of a new saccade and the end point of the previous one. Moreover, for the medium task, gaze was closer to the target at the time of response for moving items. For difficult search, fixation durations on present trials were shorter for moving items. Even at the level of eye movements, search amongst static and amongst moving items is remarkably similar. This is consistent with the framework proposed by Hulleman (2010). One clear strategy emerged: moving items are tracked over short distances. This is probably to prolong processing times and provides the robustness of visual search against item motion.

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23.328 **Measuring the stare-in-the-crowd effect using eye-tracking: Effects of task demands**

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In two studies we used eye-tracking to investigate the 'stare-in-the-crowd effect' – the easier detection of direct than averted gaze – and whether it is modulated by task demands. Stimuli consisted of four full characters (a target and 3 distractors) displayed side-by-side across the entire screen. In the first study (Location task), participants had to detect the location of either a direct- or an averted gaze target amongst opposite-gaze distractors. In the second study (Detection task), participants completed the classic stare-in-the-crowd task, detecting whether the gaze target was present or absent. In the Location task, RTs were faster for direct than averted gaze targets, but only for characters situated in the far peripheral visual fields. In the Detection task, no effect of gaze was found for RTs. In contrast, error rates were lower for detecting direct than averted gaze targets in the far peripheral visual fields for the Detection task, but not for the Location task. Thus, the stare-in-the-crowd effect was not fully replicated in either task. In both tasks, eye movements revealed a serial search for the target; the search was identical between direct and averted gaze conditions, reflecting a lack of specific strategy for direct gaze detection. However, in both studies onset times of first fixation were faster for direct than averted gaze targets in the far peripheral visual fields, mimicking the RT results of the Location task. These findings demonstrate that the detection asymmetry for direct gaze is highly dependent on target position and may be influenced by task demands. The results are discussed in the framework of the hypothetical subcortical face processing route supposed to also mediate mutual gaze detection.

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23.329 **Effective Attentional Filtering By The Union Of Two Distinct Colors: Eye-Tracking Evidence**

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When given a cue about the color of a search target people can use top-down control to constrain their search and eye movements to only objects of the target color (Williams, 1967). Here we investigate whether people can simultaneously bias their attention to target objects that were defined as having either one of two distinct colors. Participants searched for the leftward facing C among a display of 24 Landolt Cs while we monitored their eye movements. Each C was colored red, yellow, green or blue. In the critical block of trials, participants were told that the target, if present, would be either red OR blue. Reaction time data suggest that the effective set size was the total number of red and blue items, suggesting that people could constrain attention to the union of those two colors. More interestingly, the sequence of fixated items, on target absent trials, showed that participants were not searching through all the items of one color and then all the items of the other color, but were instead fixating back and forth between the blue and red items. Runs analyses and comparisons of the number of shifts from an item of one target color to an item of the other target color support the conclusion that participants create an attentional filter that was selective for the union of the red and blue items. These results suggest that people can simultaneously bias at least two distinct colors.

Binocular vision: Binocular combination and rivalry

Saturday, May 7, 8:15 am - 12:15 pm

Orchid Ballroom, Poster Boards 401 - 412

23.401 **Transition between stereopsis and binocular rivalry is based on perceived, rather than physical, orientation**

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When dichoptically viewed gratings differ slightly in orientation, they can still combine binocularly to yield perception of a surface slanted in depth. With larger differences in orientation disparity, fusion gives way to binocular rivalry characterized by perceptual alternations between the left and

right eye gratings, with no depth. Can this transition point between stereo-fusion and rivalry be shifted by induction of illusory shifts in perceived orientation? We addressed this question using a variant of the Zöllner illusion: When parallel short lines (inducers) are added to a near-vertical grating, repulsion appears between inducer and grating orientations. If stereopsis uses the perceived illusory orientations, vertical inducers should increase the perceived orientation disparity of the gratings and horizontal inducers should decrease it. In contrast, if physical orientations are used, inducers should have no effect on the orientation disparity. Observers were asked to judge the slant of a grating composed of near-vertical contours. Orientation disparity was varied adaptively to estimate the transition in orientation disparity between stereo-fusion and rivalry. If this transition depends on perceived, rather than physical, orientation, gratings should become more often rivalrous with vertical inducers and more often fused with horizontal inducers. Seven of eight observers (six naïve) exhibited reliable differences in this depth/rivalry transition point between vertical and horizontal inducer conditions, indicating that rivalry and stereopsis can be generated from illusory orientations. A second experiment in which observers reported their subjective experiences of rivalry corroborated this finding. The magnitude of that difference was approximately twice the classical Zöllner illusion: it suggests that shifts in illusory orientation arise at a monocular level, before the resolution of rivalry and stereopsis, and adds up between eyes. We are currently investigating whether comparable interactions occur when interocular differences are induced in motion direction, which is believed to be represented at binocular levels of processing.

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23.402 Characterizing mixed percepts during binocular rivalry

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When two distinct images are presented to each eye at the same position, alternations or mixtures of those images are perceived: binocular rivalry. The properties and dynamics of unitary percepts during binocular rivalry have been well-characterized. Here, we instead focus on characterizing the properties and dynamics of mixed percepts. To do so, we presented rivaling face and house images that were large in order to promote mixed percepts. To allow for an analysis of memory effects, we used brief 5-second trials separated by 1-second inter-trial intervals. To measure spontaneous changes in mixed percepts, as well as unitary percepts, we asked participants to separately track dominant percepts within each visual quadrant by pressing or releasing four spatially-compatible buttons. Mixed percepts comprised 14 possible combinations of face-dominant and house-dominant quadrants. The results revealed two notable phenomena. First, the 14 possible mixed percepts were not reported with equal probability. Specifically, right/left half-and-half percepts were more frequent than chance level, whereas top/bottom half-and-half (and all other mixed) percepts were reliably less frequent than chance level. This result suggests that even for mixed percepts, perception is not stochastic. Second, we found a memory effect for mixed percepts. In previous binocular rivalry studies using similarly brief rivalry trials, there was a tendency for initial unitary percepts to repeat across trials. Here, participants reported systematic sequences of mixed percepts that tended to repeat across trials, demonstrating that the previously-reported memory effect continues beyond the initial percept, extending through the 3rd-6th percepts depending on the individual. This result suggests that a unitary and meaningful percept (e.g., house or face) is not necessary for a memory effect to occur in binocular rivalry. Furthermore, memory influences not only the mechanisms controlling the initial rivalry competition, but also those mechanisms underlying the subsequent spatio-temporal perceptual cascade experienced during binocular rivalry.

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23.403 Dichoptic completion, rather than binocular rivalry or binocular summation

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We define a novel percept that we call dichoptic completion. This occurs when the image shown to one eye closely resembles an amodal completion of the image shown to other eye. In this case, the perception is a form of superposition that is distinct from the result of either binocular summation or a process of rivalry when only content in one image is seen

at each location. For example, if the left eye image contains a red square partly occluding a green square, and the right eye image contains the same two squares at the same respective image locations except that the green square is partly occluding the red one, subjects typically see both squares with all the occluding and occluded borders visible, as if the squares were simultaneously transparent. At the image locations where the two squares overlap, both red and green colors are visible simultaneously, contrary to normal perception in which red and green at the same image location is difficult, but subjects never report the yellow color which would result from binocular summation. In prolonged viewing, dichoptic completion often occurs for a longer accumulated duration than rivalry. Another illustrative example involves retinal images corresponding to the two standard alternative interpretations of a Necker cube. From each interpretation, one can produce a retinal image containing the three surfaces of this cube when it is made opaque. The image produced from the other interpretation contains the other three surfaces of the cube. The dominant resulting percept is of a transparent cube containing all six surfaces, even though two luminance edges in one image cross two luminance edges in the other image in an arrangement that conventionally tends to produce binocular rivalry.

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23.404 Temporal Dynamics of Binocular Rivalry at the Blind Spot

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This study investigated temporal dynamics of binocular rivalry (BR) in which the filled-in stimulus of the blind spot (BS) competed against the physical stimulus in the fellow eye (FE). Experiment 1 compared the strength of filled-in surface to physical surface during BR. Participants tracked the percept of the BS area during rivalry between the filled-in grating at the BS and the physical grating of the FE. The frequency of short dominance durations of the FE increased and the frequency of long dominance durations of the FE decreased as compared to when rivalry occurred outside the BS. In contrast, the dominance duration distribution of the BS eye was not significantly different across the conditions. These results suggest that the weak representation of the filled-in surface modulates dominance duration distribution of the FE, consistent with Levelt's 2nd proposition. Experiment 2 investigated whether perceptual travelling waves could pass through filled-in surface at the BS. The bar stimuli with clockwise or counterclockwise grating were separately presented to the BS of one eye and the corresponding region of the FE. Participants' task was to track the percept at the cued region which was located above or below the BS during rivalry. When the BS eye was suppressed, the high contrast trigger was given at the opposite side of the tracking region to evoke travelling waves. The event-related probability function of perceiving the BS eye stimulus showed a step-like function as compared to the condition without triggers, indicating travelling waves could pass over the filled-in surface of the BS. However, when we presented rival stimuli outside the BS with a gap that had the size of the BS, this trend was not observed. These results suggest that with the aid of filled-in surface travelling waves can pass over a relatively large region like the BS.

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23.405 Binocular functional architecture for detection of luminance- and contrast-modulated gratings

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Combination of signals from the two eyes is the gateway to stereo vision. To gain insight into the stages of binocular signal processing, we studied binocular summation for luminance-modulated horizontal gratings (L or LM; 1st order) and contrast-modulated gratings (CM; 2nd order). To create LM, a sine-wave luminance grating (L) was added to dynamic 2-D band-pass noise (centre frequency 6 c/deg, rms contrast 0.2), while for CM the noise contrast was spatially modulated by the signal. In a 2AFC detection task we measured contrast thresholds (L, LM) or modulation thresholds (CM) for the signal grating (spatial frequency 0.75 c/deg, duration 0.2s) shown to one eye, to both eyes in-phase, or to both eyes in anti-phase. For LM and CM, the noise was always binocular, even when the signal was monocular. The noise was the same in both eyes, or was uncorrelated, or

anti-correlated. As in previous work, mean binocular thresholds for luminance gratings (L) were about 5dB better than monocular thresholds - close to perfect linear summation (6dB). The same was true for LM and CM: the binocular advantage was 5-6dB even when the noise was uncorrelated or anti-correlated between the eyes. The latter results imply that binocular combination for CM arises from summation of envelope responses, and not directly from summation of the carrier patterns. In all cases antiphase signals showed no summation, but in most cases also showed little or no cancellation. This is consistent with half-wave rectification of both 1st-order and 2nd-order responses before binocular summation: only like-signed signals are combined. These results support an extended FRF (filter-rectify-filter) model: FRFRB, in which two filter-rectify stages precede binocular summation (B). This architecture is strikingly similar to that proposed for cat cortex area 18 (Tanaka & Ohzawa, 2006, *Journal of Neuroscience*).

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23.406 Adaptation to interocular differences in blur

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Adaptation to blurred or sharpened images alters the physical blur level that is perceived to be in focus. These adjustments can be selective for different aberrations of the eye's optics, and could play a role in compensating neural responses for retinal image blur. We asked how adaptation adjusts to differences in blur between the eyes, which can arise from interocular differences in refractive errors. Separate left and right eye images were shown in a fused 4-deg field on a monitor viewed through a stereoscope. The images consisted of Mondrians with edges sharpened or blurred by varying the slope of the amplitude spectrum, or noise filtered to simulate different axes and magnitudes of astigmatism with constant total blur. Observers adapted for 120 sec to a blurred or sharpened image presented to one eye, or to images with different blur in each eye, with stimuli spatially jittered to avoid local light adaptation. Interleaved 2AFC staircases were then used to estimate for each eye the slope that appeared best focused or the level of astigmatic blur that appeared isotropic. Adaptation to images filtered by varying the spectral slope showed almost complete transfer between the eyes, and when different stimuli were shown in the two eyes aftereffects were dominated by the sharper image. In contrast, astigmatic blur showed significant selectivity for the presented eye, and simultaneous opposite aftereffects could be induced in each eye when adapted to blur along orthogonal meridians. The differences in selectivity could depend on whether the form of blur maintained the same (isotropic slope changes) or different (astigmatic or oriented blur) contours in the two eyes' images. Our results suggest that adaptation could selectively adjust to some but not all refractive differences between the eyes, and that the adaptation may tend to be dominated by the sharper retinal image.

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23.407 The time course of hemispheric asymmetries in perceptual selection of spatial frequency information

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Structural and functional differences between the brain's two hemispheres result in asymmetries in sensory processing. The Double Filtering by Frequency (DFF) theory (Ivry and Robertson, 1998) proposes two sequential stages of spatial and temporal frequency information processing. First, a subset of task-relevant frequencies is selected from the environment. Second, these frequencies are divided asymmetrically such that the right hemisphere processes relatively lower frequencies more efficiently and the left hemisphere preferentially processes relatively higher frequencies. Support for this theory comes primarily from measurements of reaction times to individual stimuli. Thus, it remains unclear whether this hemispheric asymmetry applies to perceptual selection from multiple stimuli containing a range of frequencies. In addition, the precise time course of the proposed two-stage filtering process has not been empirically assessed. We used binocular rivalry to measure perceptual selection of spatial frequencies from among competing alternatives over time. In binocular rivalry, conflicting images presented to the two eyes result in a perceptual alternation between the images. During each 30-second trial, subjects viewed

two rivaling orthogonal gratings, one with a spatial frequency of 1 cyc/deg and the other with 3 cyc/deg, and they continuously reported which of the grating orientations they perceived. Trials were blocked based on whether the rivalrous gratings were presented to the left or right visual hemifield. At the onset of stimulus presentation, subjects were more likely to perceptually select (i.e., report seeing) the lower spatial frequency grating in the left hemifield (right hemisphere) condition, and they were more likely to select the higher spatial frequency grating in the right hemifield condition. These results support the DFF theory. However, this interaction of spatial frequency and hemisphere dissipated after the first few seconds of viewing, suggesting that perceptual selection is initially asymmetric but that over time, the two hemispheres transition into more symmetric processing.

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23.408 Unmixing binocular signals

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Incompatible images presented to the two eyes lead to perceptual oscillations in which one image at a time is visible. Early models portrayed this binocular rivalry as involving reciprocal inhibition between monocular signals from each eye, occurring at an early stage prior to binocular mixing. However, subsequent psychophysical experiments found conditions where rivalry could occur between the two stimuli (dissociated from eye-of-origin) rather than between the two eyes, suggesting rivalry mechanisms at a higher, more abstract level of representation. Furthermore, neurophysiological recordings in monkeys found the strongest rivalry correlate in inferotemporal cortex, a high-level visual area involved in object recognition with predominantly binocular cells. These findings led to the formulation of hierarchical models of rivalry, in which previous models incorporating reciprocal inhibition between monocular image representations were augmented by an additional stage involving inhibition between higher-level, binocular representations of the two stimuli. An unresolved issue for current models is how can the separate identities of the two images be maintained after binocular mixing in order for rivalry to be possible at higher levels? Here we show that after left and right images are binocularly mixed, they can be unmixed at any subsequent stage using a signal processing algorithm, non-negative matrix factorization (NMF), previously proposed for parsing object parts during object recognition. Left and right images were combined in various proportions to form a set of different binocular mixtures, consistent with physiological observations of binocular ocular dominance classes. This set of binocular mixtures was then fed into the NMF algorithm, which regenerated the original left and right images from them. I suggest that binocular rivalry occurring at higher visual levels may be related to mechanisms of shape representation during object recognition rather than mechanisms of stereopsis.

23.409 Binocular rivalry between spiral space stimuli in human observers: Expanding stimuli dominates over contraction and rotation.

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During binocular rivalry, monocular stimuli compete for perceptual dominance. It is thought that rivalry arises from competitive interactions at different levels in the visual system between groups of neurons holding monocular representations of visual stimuli (Blake and Logothetis, 2002). It has been shown that increasing the strength of a visual representation by attending to it or increasing its contrast prolongs the corresponding rivalry period (Chong and Blake 2002). We hypothesize that existing biases in the representation strength of expanding spiral stimuli in area MSTd shall prolong their corresponding rivalry periods (predominate) compared to other spiral motion types. In MSTd, expansion neurons outnumber contraction neurons by a ratio of ~2:1, and rotation neurons by a ratio of ~3:1 (Duffy & Wurtz, 1991; Graziano et al., 1994; Saito et al., 1986; Tanaka & Saito, 1989). We tested this hypothesis by measuring rivalry periods for combinations of expanding, contracting, and rotating random dot patterns (RDPs) in seven human observers. The RDPs were presented monocularly through a stereoscope and were matched for contrast and speed. We found that: a) expansion generally predominated over contraction (Wilcoxon Signed-Rank test, Left Eye (LE): p=0.0156; Right Eye (RE): p=0.0781), and rotation (LE: p=0.02345; RE: p=0.02345), b) contraction generally predominated over rotation although it did not reach statistical significance (LE: p=0.1485; RE: p=0.1953), and c) clockwise vs. counterclockwise rotations showed non-sig-

nificant differences (LE: $p=0.8125$; RE: $p=1.000$). In a control experiment we measured rivalry periods for linearly moving RDPs in the four cardinal directions and found no differences in durations amongst these motion types. However, when comparing the rivalry periods between linear and complex motion types, periods were longer for spiral stimuli ($p<0.01$). Our results suggest that biases in the representation of different spiral types by MSTd neurons can influence the competitive interactions underlying visual motion binocular rivalry.

23.410 The effect of interocular delays on the perception of 3D movies

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Challenging the visual system with incongruent binocular information reveals the physiological constraints of visual perception. One type of incongruence is the temporal delay between corresponding binocular frames in a stereoscopic condition. With the recent invasion of 3D technology, this question has also become practical. Interocular delays also play a role in several eye diseases, causing perceptual distortions such as the Pulfrich effect. Although the tolerance of the visual system for interocular delays during stereo perception has been extensively studied, results are extremely diverse, almost incommensurable. While disparity-sensitive neurons in V1 display <20 ms time window of stereo fusion between binocular signals, psychophysical studies demonstrated a 30-100 ms delay tolerance. Here we asked human observers to rate the 3D quality of percept after watching 3D movies under various binocular delay and speed conditions. The delays were varied between 0 and 2 s in 33 ms increments, and the movies were viewed at six different speeds, randomized. We found that for natural scenes the visual system is able to merge frames across 500 ms (maximum 2 s), a much longer delay than reported earlier. We computed various image statistics to make sure that the average pixel lifetime was a fraction of 500 ms, thus corresponding pixels changed their hue and luminance asynchronously within intervals while 3D percepts were maintained. In order to explain the sustained 3D experience despite long delays we considered a number of factors, such as top-down effects, anticipation, inhomogeneity of motion vectors in space and time, attention and eye dominance. The flexibility of the visual system in buffering parallel visual streams over 500 ms and the ability of merging them despite the mismatch between simultaneous frames calls for a revision of the bottom-up models of 3D perception and suggests a mental editing capacity yet to be explored.

23.411 Perceptual misbinding of color and motion induced by modulative effects of preceding stimuli on binocular rivalry

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This study investigated how color and motion are integrated during binocular rivalry, by taking advantage of previous findings that binocular preceding stimuli phenomenally suppress one of the rivalrous stimuli having the same stimulus feature (e.g., Abe et al., VSS2010). Specifically, using moving chromatic gratings, this study examined how the preceding stimulus sharing color and/or motion with rivalrous stimuli modulated subsequent rivalry resolution. Rivalrous test stimuli were green-black rightward-moving vs. red-black leftward-moving gratings (540 msec). The preceding stimulus (1080 msec) corresponded to one of the rivalrous stimuli under the same-combination condition, whereas color and moving direction were combined differently under the different-combination condition (i.e., it was either green leftward-moving or red rightward-moving gratings). The results showed that modulative effects of the preceding stimulus produced exclusive dominance on most of the trials (> 75%) under the same-combination condition; i.e., one of the rivalrous stimuli having different features from the preceding stimulus became dominant. Furthermore, very frequent misbinding of color and motion (about 60% of trials) were found under the different-combination condition. The misbound percept consisted of the features opposite to those in the preceding stimulus; e.g., a green leftward-moving preceding stimulus induced the percept of a red rightward-moving grating during subsequent rivalry, although the actual rivalrous stimuli were green rightward-moving and red leftward-moving

gratings. These results suggested that color rivalry was resolved independently of motion rivalry. However, when the preceding stimulus was either achromatic moving gratings or static chromatic gratings, which shared only motion or color with the rivalrous stimuli, exclusive dominance was predominant (about 60% of trials) and misbinding occurred infrequently (<15%). Thus, color and motion were more associated under these conditions. Taken together, the present results indicated that although color and motion rivalry can be resolved independently, additional conditions need to be met for color and motion to be dissociated.

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23.412 Predictive context biases perceptual selection during binocular rivalry

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Prediction may be a fundamental principle of sensory processing: it has been proposed that the brain continuously generates predictions about forthcoming sensory information. However, little is known about how prediction contributes to the selection of a conscious percept from among competing alternatives. Here, we used binocular rivalry to investigate the effects of prediction on perceptual selection. In binocular rivalry, incompatible images presented to the two eyes result in a perceptual alternation between the images, even though the visual stimuli remain constant. If predictive signals influence the competition between neural representations of rivalrous images, this influence should generate a bias in perceptual selection that depends on predictive context. To manipulate predictive context, we developed a novel binocular rivalry paradigm in which orthogonal rivalrous test gratings were immediately preceded by rotating gratings presented identically to the two eyes. One of the rivalrous gratings had an orientation that was consistent with the preceding rotation direction (it was the expected next image in the series), and the other had an inconsistent orientation. We found that human observers were more likely to perceive the consistent grating, suggesting that predictive context biased selection in favor of the predicted percept. This prediction effect depended on only recent stimulus history, and it could be dissociated from another stimulus history effect related to orientation-specific adaptation. Since binocular rivalry between orthogonal gratings is thought to be resolved at an early stage of visual processing, these results suggest that predictive signals may exist at low levels of the visual processing hierarchy and that these signals can bias conscious perception.

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3D perception: Contours, shading and texture

Saturday, May 7, 8:15 am - 12:15 pm

Orchid Ballroom, Poster Boards 413 - 423

23.413 Interpreting line drawings of smooth shapes

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Line drawings can be an effective way of conveying the 3D shape of an object. Computational models for line drawing interpretation have mainly dealt with "blocks world" drawings, with clean lines corresponding to the sharp creases between faces. However, humans can interpret drawings of blobby, "organic" objects, where there are no well defined faces, and where the lines do not lie on creases. Moreover, humans can deal with lines that are broken, noisy, and and disconnected. We have developed a computational model that mimics human performance on this kind of imagery. To produce a drawing interpretation, the system uses a novel combination of techniques from object recognition and 3D shape modeling: a machine learning stage first estimates the figure-ground direction of each line, and a shape optimization stage then finds a smooth surface that satisfies the figure-ground constraints. The system requires no initial labeling or processing by a human. We compare the results of our system to the surface orientations reported by humans when shown computer-generated drawings of known 3D shapes. We can thus compare our results both against the aggregate human perception of each drawing, and against the original 3D shape from which the drawing was made. For the restricted class of smooth

shapes, we find that the algorithm produces very similar interpretations to humans, both where the humans interpret the original 3D shape accurately and where they do not. This success suggests that the strategies used by the algorithm may be similar to those employed by humans.

23.414 The perception of 3D shape from contour textures

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One of the most common methods for depicting curved surfaces in mechanical drawings and optical art is to cover the surface with a series of parallel contours. When these contours are viewed from an appropriate vantage point, it produces a compelling perception of 3D shape. In an effort to better understand this phenomenon, we have developed a new computational analysis that is designed to estimate the shape of an observed surface from the optical projections of its contours in a 2D image. This model assumes that contours on a surface are generated by a series of parallel planar cuts (Tse, 2002), and it estimates the relative depth between any two surface points based on the number of contour planes with which they are separated, and the apparent 3D orientations of those planes. A psychophysical experiment was performed in an effort to compare the model predictions with the perceptual judgments of human observers. Stimuli consisted of sinusoidally corrugated surfaces with contours that were oriented in different directions. Horizontal and vertical scan lines in these images were marked by a row of nine equally spaced dots. An identical row of dots was presented against a blank background on a separate monitor, each of which could be moved perpendicularly with a handheld mouse. Observers were instructed to adjust the dots on the second monitor in order to match the apparent surface profile in depth along the designated scan line. The results revealed that observers' shape judgments are typically compressed and/or sheared relative to the ground truth, and these distortions can be simulated with our model by computing relative depths using an incorrect estimate of the 3D orientations of the contour planes. The results cannot be fit, however, using models that assume contours are lines of curvature (Stevens, 1981) or surface geodesics (Knill, 2001).

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23.415 Analysis of the combination of frequency and orientation cues in texture 3D shape perception.

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Visual perception of shape from texture has led to numerous studies to unravel which cues are effectively used by observers. Recently, Li & Zaidi (2004 Journal of Vision 4 860-878) have suggested distinguishing between frequency and orientation cues. Following this distinction, we evaluate the contribution of frequency gradients and orientation flow for the perception of shape from texture. We present several experiments based on purposely-designed stimuli. Each stimulus represents a cylinder covered by a homogenous texture composed of Gabor patches. The cylinder is presented upright with different radius and is viewed under perspective projection. Importantly, the frequency of each Gabor patch is determined by the local spatial frequency gradient defined by the projection. Similarly, the orientation is determined by the local vanishing point induced by the orientation flow along the direction of the patch. Thus, we are able to independently manipulate the frequency and the orientation gradients in order to obtain a texture with a specific combination of cues. We synthesize textures presenting only a frequency gradient or an orientation gradient or both gradients. For each texture, a shape discrimination task and an absolute shape judgment task are performed. We find that orientation-defined textures are better discriminated than frequency-defined textures. In addition, a perturbation analysis reveals that orientation flow dominated over frequency gradient. These results validate our stimuli to study the perception of shape from texture and the decomposition of the texture cue into elementary components.

23.416 Position selectivity of mechanisms underlying the perception of 3D shape from orientation flows

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Previously, using the psychophysical technique of selective adaptation, we've provided evidence for extra-striate 3D shape-selective neural mechanisms that are invariant to texture pattern (Filangieri & Li, 2009). This was done by eliciting negative 3D shape aftereffects from stimuli in which the 3D concave or convex shape was defined by luminance-modulated, con-

trast-modulated, and illusory orientation flows. The goal of the current experiment was to test whether 3D shape-selective mechanisms are invariant to the exact retinal position of the stimulus. If these mechanisms are position-invariant, we would expect negative shape aftereffects even when the adapting and test stimuli are misaligned in space. We tested for shape aftereffects using horizontally sinusoidally corrugated stimuli in which the 3D concave or convex shape was conveyed by luminance-modulated orientation flows. Adapting and test stimuli were misaligned horizontally by 2 degrees such that the corrugations of adapting and test stimuli were 180 degrees out of phase. In a separate control condition, adapting and test stimuli were misaligned vertically by 2 degrees such that the corrugations of adapting and test stimuli were in phase. As expected, our results show negative shape aftereffects in the vertical conditions we tested. We also found evidence for positive shape aftereffects in the horizontally misaligned conditions that are consistent with adaptation of position-selective mechanisms. Together, these results suggest that 3D shape-selective mechanisms that respond to luminance-modulated orientation flows appear to be sensitive to shifts in position of 2 degrees, which in our experiment span a single convexity or concavity. Preliminary results in an additional experiment suggest that this position-selectivity may extend to neural mechanisms sensitive to orientation flows defined by contrast modulated and illusory orientation flows.

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23.417 Face priors overcome shape-from-motion signals in the rotating hollow face illusion

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OBJECTIVE: In the rotating hollow face illusion (HFI), viewers perceive a hollow face as a convex face rotating in the opposite direction. Our objective: compare the strength of data-driven motion-perspective signals (faster-is-closer) to schema-driven influences (faces-are-convex) in the HFI. **BACKGROUND:** Meng and Zaidi (VSS 2008) obtained evidence for strong motion-perspective depth effects: two half-cycles of a sinusoidal corrugation (one concave, one convex) rotating about the zero crossing both appear convex; while rotating about their apex, both appear concave. HFI studies generally use masks rotating about an axis through the center of gravity. This generates retinal velocities that are larger for the nose than the cheeks and eyes. These relative velocities signal that the nose is closer, enhancing the illusion. We varied the relative velocities by placing the rotation axis at various distances from the nose. **METHODS:** We used: (1) physical masks painted realistically on both sides (convex and concave) rotating on a turntable; (2) computer-generated painted virtual masks (using FaceGen), rotating as in (1), allowing a greater range of axis-to-nose distances. We varied the relative velocities of the features, including conditions where the nose had a smaller velocity than the cheeks and eyes. We estimated the illusion's predominance as the time spent in the illusory percept divided by the total time that the mask had its concave side facing the observer. **RESULTS:** In both experiments, the concave face was seen as convex for significant intervals, even when the nose had lower velocity than the cheeks and eyes, which should reinforce the concave percept based on motion perspective. There was relatively little variation of the illusion predominance as the axis position was varied.

CONCLUSIONS: The results provide evidence that, in the HFI, the top-down prior of convex faces dominates the velocity-driven 3D shape-from-motion signals resulting from object rotation.

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23.418 Classification images reveal lighting prior for shape-from-shading

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Studies of shape-from-shading have shown that humans tend to assume that stimuli are lit from above. Such studies typically use ambiguous stimuli; the stimulus orientation for which perception is bi-stable indicates the

preferred lighting direction. We take an alternative approach using classification images as a tool to probe the lighting prior. This technique uses either target stimuli embedded in a strong noise mask or noise only stimuli and asks observers to detect some target feature. Noise samples are accumulated according to the observers' responses and the resulting images represent the observer's template for the target in question. We asked observers to identify the image containing a small bump (they were told that the diameter would be around 5cm / 2.5deg) in a 2-IFC task in which only 1/f noise images were shown (no target was presented). Observers were not shown example targets but rather were asked to imagine the image that would be formed by frontal viewing of a shape presented to them, once only, as a profile sketch. Observers' templates were derived by averaging the noise samples leading to positive responses and subtracting the average of those samples that were not selected. There were two control conditions large bumps (notional diameter 8cm) and white disk. Templates were typified by approximately Gaussian white blobs. We measured the position of the luminance peak in each template. Peaks in 'bump' templates were typically offset from the centre compared to 'white disk' templates (mean offset for 'small bump' = 0.25deg). 'Large bump' templates had larger offsets (~0.5deg). There was a tendency luminance peaks to be above centre in 'bump' templates. This result is consistent with a template based on a shaded bump lit from above. Supported by EPSRC Grant EP/F026269/1
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23.419 Shape from contours constrains shape from shading

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When light illuminates a 3D body it generates a luminance distribution (shading pattern) that can be calculated using the irradiance equation. However, reconstructing the 3D shape from a given luminance distribution is not trivial. Mallot (2000) showed that for 1D luminance distributions the irradiance equation can be inverted and solved for the depth profile, in some cases analytically. The solutions are not unique but involve families of curves. Therefore the question arises how the visual system 'chooses' particular shapes as perceived depth profiles. One possible constraint is the shape of the contour of the shading pattern. On the 2009 VSS I reported that this shape can indeed affect the perceived depth profile. Here I report new mathematical analyses and a new experiment using as stimuli three-cycle sinusoidal luminance distributions bounded by 12 differently shaped contours. The tasks of the 102 subjects for each of the 12 stimuli were a) to choose the corresponding perceived depth profile from a presented set of 17 profiles depicted as outline sketches without shadings, b) to rate its depth extent on a scale from 0 to 3, and c) to judge its illumination direction by choosing from 5 possibilities spanning the range from 0 to 180 degrees. The results showed surprisingly strong, generally consistent and qualitatively diverse effects of different shapes of contours of otherwise identical shading patterns on their perceived 3D shapes. Many aspects of the perceptual effects can be accounted for by a mathematical result by Koenderink (1984), who showed that features of the local shape of smooth 3D bodies can be deduced from the 2D shape of their bounding contours. When contoured shaded regions generate depth percepts, the effects of contour shapes (contour constraints) interact with the effects provided by the interior structure of the shading patterns (shading constraints).

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23.420 Grouping modulates contextual biases in 3D perception

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The visual system can resolve ambiguity about 3D structure by using information from the context and by establishing relationships among objects. Contextual influences on slant perception are evident in contrast biases where the slant difference with contextual stimuli is enhanced. Relationships among objects, on the other hand, are established by grouping principles. Phenomena of contrast biases and grouping in 3D perception have traditionally been treated separately, but are related because both establish relations between an object and its context. Moreover, they have both been linked to the neural phenomenon of surround suppression (Schwartz, Hsu & Dayan, 2009). We investigated whether contrast biases in slant perception are related to mechanisms of grouping and segmentation. We presented a central slanted surface surrounded by a ring of eight slanted surfaces.

Natural borders between surfaces were obscured with a black frame. Three grouping conditions were created: one where all surfaces were defined by the same texture, one where the surrounding surfaces had a different texture, and one where the central surface was presented on a different depth plane. Contrast biases were induced by having observers perform a shape discrimination task where the reference and test surface were presented with a surround of equal or differing slant. In addition, perception of the isolated central surface was measured. Biases and discrimination thresholds were measured using a staircase procedure. We found a clear contrast bias when the test and reference surface were presented with a different surround. Importantly, this contrast bias was reduced when the surrounding surfaces were differentiated from the central surface in texture or depth plane. This shows that grouping modulates contextual influences in slant perception. The implication that contrast biases in 3D perception are related to a mechanism of grouping and segmentation provides a completely novel take on 3D perception.

23.421 Symmetry facilitates 3D shape discrimination across changes in viewpoint

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Perceiving 3D shape constancy across changes in viewpoint is a challenging problem. Some researchers have argued that the presence of symmetry could allow viewpoint invariant perception of 3D shape, even from a monocular image (Vetter et al., 1994; Pizlo & Stevenson, 1999). We tested whether symmetry can facilitate shape discrimination for smoothly-curved, solid 3D objects. Symmetric and asymmetric random shapes were generated to have the same angular power spectra, expressed as spherical harmonics. Objects were presented in three viewing conditions: shading-only, stereo-only, and combined shading and stereo. Shaded objects were illuminated by a diffused point light source, and a mirror haploscope was used to present binocular images. Objects were presented sequentially and observers judged whether the two shapes were same or different. The test objects were either the same orientation or differed by a rotation in depth of $\pm 15^\circ$, $\pm 30^\circ$, or $\pm 60^\circ$ relative to the standard object. In all conditions, we found that shape discrimination performance decreased with rotation in depth. Overall, shape discrimination for symmetric objects was better than for asymmetric objects. We also observed an interaction between symmetry and viewing condition. For asymmetric objects, binocular viewing provided a significant benefit, while for symmetric objects, performance in monocular and binocular conditions was equivalent. The results suggest that structural constraints like symmetry are important for viewpoint invariant perception, and that stereo information may not be essential for shape perception of structured 3D objects.

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23.422 Recovering a 3D shape from a single 2D image of a generalized cone

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Human observers perceive 3D shapes very accurately even from single 2D images. However, recovering a 3D shape from a single 2D image is an ill-posed problem. There exist infinitely many 3D interpretations of the 2D image. In order to solve this problem, a priori constraints about the 3D shape are required. In our prior studies (Li, Pizlo & Steinman, 2009; Sawada, 2010), we proposed a computational model that recovers 3D shapes from single 2D images using the following constraints: 3D mirror-symmetry, maximum 3D compactness, minimum surface area and maximum planarity of contours. Note that even though most objects in our everyday life are mirror-symmetric, their parts are adequately represented by generalized cones (GC), which are characterized by translational, rather than mirror symmetry. In this study, we propose a computational model which recovers shapes of 3D GCs from single 2D images. Our GCs are produced by swiping a planar closed curve (cross section) along a planar axis with the following constraints: all cross sections in a given GC have the same shape, but not necessarily constant size. Each cross section is perpendicular to the tangent of the axis. With these constraints, a single 2D orthographic image of a GC determines the 3D shape up to one unknown parameter - aspect ratio. The aspect ratio of the recovered GC is selected by maximizing a weighted average of 3D compactness and surface area. Performance of this model will be compared to the performance of the subjects in a 3D shape adjustment task.

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23.423 Neon Color Spreading to Two Dimensional Manifolds and Three Dimensional Solids

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Varin (1971) and van Tuijl (1975) described a striking color illusion/effect (neon color spreading) (NCS): Consider thin rectangular spokes radially emanating from a central point such that the inner $\sim 1/3$ is red while the remainder of each spoke is black. There is the vivid perception of a filled in red disc (radius the length of the red portion of the spokes). We wondered if NC could be made to spread into three dimensional figures. Many initial attempts were in vain: Using red/black spokes as in the original effect such that perspective caused one to perceive the surface of a sphere—not just a disc—we did not see neon color spread to this surface, even when this was enhanced with stereo fusion. Even when we used stereo and multiple perspective cues to have color spread to the surface of a small sphere inside a cube we did not see spreading to the sphere, just the perception of a planar colored disc. Using stereo and a color spreading effect (Huang et al, VSS Demo Night 2010) we were finally able to obtain NCS to planes coming out of the screen/page, and we were also able to obtain NCS to two-dimensional manifolds (e.g., the surface of a torus) using modal/ amodal completion figures of Tse (1998). Liinasuo et al (2000) noted figures in which they saw NCS onto two-dimensional manifolds, but we see the manifolds without the NCS. Using the watercolor effect Tanca and Pinna (2008) were able to get NCS to two-dimensional manifolds. We were able to achieve NCS into three-dimensional solids using stereo and the watercolor effect, the interior “blob” figures set so as delineate the surface and interior locations of a sphere. These investigations raise consciousness generally about the perception of three-dimensional solids.

Attention: Tracking

Saturday, May 7, 8:15 am - 12:15 pm

Orchid Ballroom, Poster Boards 424 - 441

23.424 When vision loses its “grip” on tracked objects: Lessons from studying gaze-to-item dynamics

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We use a unique gaze-to-item analysis to study when vision “loses its grip” on tracked objects. Important insights can be gained by looking at spontaneous tracking failures and those that occur during uninterrupted vs. interrupted tracking (such as when we blink our eyes or objects overlap each other). We generate an explicit trace of eye-movement paths and each of the eight item positions recorded over the course of each of (138 - 5 sec) multiple object tracking (MOT) trials. Temporal profiles of scan- and item-paths, help identify sources of tracking failures obscured by the aggregated accuracy measures typically recorded at the end of each trial. We show tracking failures from object crowding, and subsequent gaze-switching from targets to non-target items. We also show how spontaneous switching across tracked objects is common, and does not impair tracking accuracy (See Elfanagely et al, VSS 2011). Finally, we show when object tracking is disrupted briefly (<1 sec), our gaze continues to remain close to those items tracked just prior to their disappearance (See Alley et al, VSS 2011). Because we have tested conditions where gaze and attention are correlated, scan path patterns are easily understood in terms of gaze and attentional indexing as two systems coordinating to effectively track objects.

Acknowledgement: Rutgers University

23.425 Tracking objects and tracking our eyes during disrupted viewing

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We are studying how people track objects, and how eye-movements and attention contribute to this ability. We extend Keane and Pylyshyn (2006) and Aks, Pylyshyn, Haladjian et al., (2010), research on multiple object tracking (MOT) during disrupted viewing to learn whether the visual system encodes the position of tracked objects. Observers blinked their eyes when a brief tone was presented midway into each trial where they were tracking 4 of 8 identical items. Eye-blinks triggered item disappearance and the onset of a mask that blocked the display of items (for up to 1 second). During their disappearance, objects either continued moving, or halted until their reappearance. Better tracking occurred when items halted (or were displaced further back along their quasi-random motion trajectory) suggesting that the visual system refers back to past position samples to guide where tracked items are likely to reappear. In the current study, we explore the role of eye-movements in MOT. Our gaze-to-item analysis, described in Aks et al., VSS 2011, shows parallels between eye-movements and MOT performance. Gaze tends to remain near targets that were tracked just before the blink when objects disappeared. This gaze- to-item linkage was reliable across “halt” trials, highly idiosyncratic on “move” trials, and intermittent during the uninterrupted part of the tracking task. Switching gaze across targets, accounting for the intermittency, was surprisingly common and often spontaneous (see Elfanagely et al., VSS 2011). These results suggest that different eye-movement strategies can be used to maintain mental links to tracked objects.

Acknowledgement: Rutgers University

23.426 Close encounters of the distracting kind: Explaining the limits of visual object tracking

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Why can we track only so many objects? We addressed this question by asking when and how tracking errors emerge. To test the hypothesis that tracking errors are predominantly target/non-target confusions emerging from close encounters, we compared standard multiple object tracking trials with trials wherein a non-target turned a random color whenever it approached within 4° of a target. This manipulation significantly improved performance by alleviating the correspondence challenge of a close encounter. In a second experiment, we systematically varied the minimum distance for color changes, and surprisingly, we found no benefit for distances smaller than 3.5°, and similarly, no additional benefit at larger distances. Providing color information below a critical distance could do nothing to alleviate errors already accrued; and providing color information beyond that distance tried to help where help was not needed. Indeed, in a third experiment, inducing color changes whenever non-targets were between 4° and 5.5° of a target, but not below, also produced no advantage. In a fourth experiment, parametrically restricting the minimum distance at which items could approach resulted in all improvements gained at about 4°, providing independent evidence for a critical confusion distance. A fifth experiment compared tracking of four and five targets, varying the number of non-targets so that the total number of close encounters was nearly equal. This produced equal tracking performance, implying that the number of close encounters, not targets, constrain subsequently measured performance. Further experiments explored the effects of speed and target load on the critical close encounter distance. Taken together, these experiments suggest that uncertainty about target location imposes the primary constraint on tracking by leading to confusions with non-targets. But the degree of this uncertainty is fixed, and not dependent on display parameters or tracking load.

23.427 Center-looking suggests grouping rather than separate attentional foci in multiple object tracking

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Previous research has shown that, when asked to track multiple moving targets among identical distractors, people often look at the center of the group of targets (Fehd & Seiffert, 2008, Cognition). There are two possible explanations for the center-looking tendency. One possibility is that targets are grouped first and then attention and gaze are directed toward the group. The other possibility is that separate attentional foci are directed toward each target and gaze settles in the center as the equidistant point. To test these hypotheses, we biased attention to one target over the others to measure whether gaze would shift from the center toward the more-attended target. Participants tracked three targets moving among distractors for 5 seconds and attempted to select the targets at the end of each trial. Experiment 1 manipulated attention with a goal-driven approach by giving participants points for correct target selections. To bias attention, one target was worth more points than the other two. Experiment 2 took a stimulus-driven approach by varying the contrast of the targets. To bias attention, one target was a different contrast (either higher or lower) than the other two. The results showed that participants were significantly more accurate at selecting the target that was worth more points (Exp. 1; $t(11) = 3.2, p < .01$) and the target with unique contrast (Exp. 2; $t(10) = 2.549, p < .05$) than the other targets, suggesting that the manipulations of attention were successful. However, participants continued to look at the center of the group of targets in both experiments, rather than off-center towards the more-attended target. These observations provide no support for the theory that people allocate weighted attentional foci to targets, but are consistent with the conclusion that tracking multiple objects involves attending to targets as a group.

23.428 Eye-movement dynamics of object-tracking.

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Tracking requires maintaining a link to individual objects as they move around. There is no need to maintain a record of object position over time; all that is needed is maintaining a connection, or index, to target items as they move (Pylyshyn, 2004). Yet, how well we maintain links is undoubtedly reflected in tracking behaviors. Both the time course and pattern of eye-scanning used in multiple object tracking (MOT) may help us understand how humans track objects. By analyzing MOT dynamics, we explore why better tracking occurs when objects halt during their disappearance (Keane & Pylyshyn, 2006), and how the visual system maintains a memory of prior object-positions. We use the MOT task described in (Alley et al. 2011), and "gaze-to-item" analysis measuring relative distance between eye-positions and each of 8 changing item positions (4 are tracked targets). We also use Recurrence Quantification Analysis (RQA) to determine whether recurring eye-movement patterns play a role (Webber & Zbilut; 1994). How smooth and repetitive are gaze paths? Fehd & Seiffert (2008) report that gaze follows the center of a group of targets, and that this "centroid" strategy reflects tracking a global object formed by grouping. This leads to a prediction that such a "center-looking strategy" should be smooth since the centroid moves with the average instantaneous position of independently moving objects. However, among gaze dynamic patterns that we found, one surprising result is the pervasiveness of switching gaze across items. Such frequent switching occurs spontaneously, and under crowding conditions, and is consistent with the alternative indexing account that individuated objects are tracked separately. By focusing only on aggregated positions, we may be masking important dynamics. Perhaps most significant are recursive scan paths of which switching behavior is a critical component. This may reflect iterative coding for sequences of prior object positions.

23.429 The effect of speed on multiple object tracking: Is it due solely to the number of close target-distractor interactions?

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Several studies have shown that multiple object tracking (MOT) performance declines as the speed of the objects increases. One possible explanation for this is that increases in speed increase the number of times that targets and distractors pass close to each other ("close encounters"), resulting in more target-distractor confusions (e.g., Franconeri et al., 2010). Other possible explanations are that more attention is required to track fast-moving objects (e.g., Alvarez & Franconeri, 2007) or that it is more difficult to predict the future locations of fast-moving objects (Tomblu & Seiffert, 2008). The present study investigates whether MOT performance is impaired by increases in speed that do not increase the number of close encounters. On each trial, there were six pairs of disks, and each pair rotated about the pair's midpoint, and about the center of the display. Observers tracked six target disks, one from each pair. The speed of rotation about the center of the display was the same for all disks on a given trial, and had four levels that were varied across trials. In these displays, increasing the speed of rotation about the center of the display increases the disks' speeds, but does not increase the number of close encounters. Tracking performance was found to decline as the speed of the disks increased. This demonstrates that even when the number of close encounters is held constant, speed still has an effect. While many studies have found that close encounters affect MOT, the results of the present study suggest that the increased number of close encounters is not the only cause of the impairment of MOT at higher speeds. Other factors, such as the increased attentional allocation required and the increased difficulty of predicting future locations, probably play roles in the reduction of tracking at higher speeds as well.

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23.430 In multiple object tracking, at high speeds one may only be able to track a single target—even if no crowding occurs

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To assess the speed limit for tracking moving objects with attention, first some blobs are designated as targets, then they and other identical blobs travel about. After a variable tracking period, participants must indicate which blobs had been designated as targets. If more blobs are designated for tracking, the maximum speed yielding accurate performance decreases. However, Franconeri et al. (2008; 2010) suggested that the decrease in high-speed performance with more targets is entirely attributable to crowding—in most studies, at higher speeds objects pass near each other more frequently. We assessed the speed limit for tracking one and for tracking two targets. In each of two concentric circular trajectories, two blobs traveled. Within a trajectory, the two blobs were always on opposite sides of fixation. One blob in one trajectory (one-target condition) or one blob in each trajectory (two-target condition) was precued. Separation between the trajectories was varied to assess any effect of crowding. RESULTS. The average speed limit (68% threshold) of six participants was substantially higher for tracking one target (1.9 rps) than for tracking two targets (1.5 rps), even when crowding was avoided with large separation. The slowness of the two-target limit found is similar to that predicted (1.6 rps) if each participant tracked only one target at high speeds, guessing when they picked the wrong one to track. To further investigate what causes the speed limits, we exploited the finding of hemisphere-specific tracking resources (Alvarez & Cavanagh 2005). Two targets were in either the same hemifield or different hemifields. The speed limit was significantly lower (six participants) for targets in the same hemifield than in opposite hemifields, consistent with the involvement of independent resources. Availability of such resources may set the severe speed limits on tracking documented here.

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23.431 **How the imprecision of spatial knowledge constrains multiple object tracking**

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Most theories assume that attention imposes the primary constraint on the number of objects one can track, either through a limited number of foci, or a limited amount of attention. Yet tracking must also rely on updating one's knowledge of object locations, knowledge that is probably never perfect, even for one object. Could inherent imprecision in spatial knowledge be the only factor limiting tracking? We measured the imprecision in representations of location in displays with featurally identical targets and non-targets. After a tracking period, all items disappeared. In half of trials, all reappeared again, and targets were identified, affording a measure of tracking performance. In the other half of trials, all but a single target reappeared. Participants clicked in the location of the absent target, affording a measure of the imprecision in their spatial knowledge. (A separate experiment found no tracking deficit for items that disappeared momentarily compared to ones that did not). We tested loads of as many as eight targets among variable numbers of distractors, and we used a separate experiment with 16 targets to identify (and exclude) responses that likely came from a distribution of mostly guesses. Collectively, five experiments showed that imprecision was invariant with respect to the number of targets successfully tracked, their sizes, and even whether they moved or not. Moreover, imprecision was not affected by increasing numbers of non-targets, though tracking performance was. And imprecision did not increase for more crowded displays, though tracking performance suffered considerably. These results suggest that inherent imprecision in spatial knowledge imposes the primary constraint on tracking. High target loads, dense and crowded displays do not consume more attention or exhaust available foci. They simply increase the probability that inherently imprecise location knowledge will lead to tracking errors.

23.432 **Multiple object tracking, working memory capacity, and motivation**

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Being able to track moving objects is an important ability for daily navigation through our visual world; however, individuals may vary in their ability to track objects (Drew & Vogel, 2008). Typically, this variation in tracking ability has been examined using higher level cognitive processes (Oksama & Hyona, 2004), though it is not clear what role motivation may play in influencing performance on visual tracking tasks. In this study, we investigated the influence of verbal working memory capacity and self reported motivation on multiple object tracking performance. Fifty-one participants completed a battery of cognitive psychology measures, including a multiple object tracking (MOT) task, an automated operation span task (Ospan), and a questionnaire related to motivation (Sundre, 1999; Wolf & Smith, 1995). For the MOT task, participants tracked two, three, four, and five objects, and an overall measure of tracking performance was computed for each participant. For the Ospan task, the number of correctly solved math problems and correctly recalled items in the proper order was used as a measure of working memory capacity. Finally, the motivation questionnaire consisted of 10 items that were combined into a single measure of overall motivation (Cronbach's alpha > .80). While others have argued for the role of higher level cognitive processes in predicting visual tracking performance, the current study found no significant effect of working memory capacity on MOT performance. Interestingly, motivation was significantly correlated with MOT performance, $r(49) = .322$, $p < .05$, as well as with working memory capacity, $r(49) = .306$, $p < .05$. This suggests that a verbal measure of working memory capacity may not predict visual tracking performance as well as self reported motivation. Future studies should examine spatial working memory tasks and other measures of motivation to further understand their influence on visual tracking performance.

23.433 **Visually guided self-motion does not impair multiple object-tracking**

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Moving about the world seems to involve a process of keeping track of one's own location in space that interferes with the ability to track moving objects (Thomas & Seiffert, 2010, Cognition). Here, we manipulated visual cues to self-motion to determine whether the cost of self-motion on tracking could be eliminated. As in the previous work, participants tracked 3 red targets among 3 red distractors, all moving randomly within a confined region of a virtual environment, then responded to a target-or-distractor probe at the end of each trial. While tracking, participants stepped in place or walked in a quarter circle around the tracking region. For this experiment, we changed the background so that it was a gray, featureless ganzfeld and added 3 black dots to manipulate the visual cues to self-motion. When these black dots were stationary, tracking accuracy was higher for stepping (90% correct) than walking (77%), $t(11) = 3.7$, $p < .005$. This replicated our previous work showing that even when reliable visual cues are given, self-motion impairs object tracking. When the black dots moved randomly like the distractors, the same result was obtained (stepping = 92% and walking = 77%, $t(11) = 3.7$, $p < .005$). This result suggests that even when no stationary visual cues are present, updating from self-motion impairs object tracking. However, when the black dots guided self-motion by rotating along arcs concentric to the participant's motion, self-motion did not impair tracking (89.1% and 88.9%, $t < 1$, ns). Interestingly, this was true whether the dots rotated in the same or opposite direction as the participants. As a whole, these data suggest that multiple object tracking and self-motion share a resource related to updating locations in space, but that visual guidance of self-motion can reduce the dependence on this resource.

23.434 **Cross-attribute object trackings are much slower than within-attribute trackings**

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Verstraten et al. (2000) examined the temporal limit for attentive tracking of an object within a circular ambiguous apparent motion display consisting of several luminance-defined discs. They found that the limit was 4-8 Hz, much lower values than for first-order motion detection. They argued that this demonstrates a higher-level involvement. To clarify the nature of this higher-level involvement, we examined the temporal limits for attentive tracking by using stimuli defined by several different attributes (luminance, binocular disparity, motion direction, and flicker). The experiment was conducted in either within-attribute (motion between arrays defined by the same attribute) or cross-attribute (motion between arrays defined by luminance and those defined by the other attribute) conditions. Two circular arrays of four rectangle objects (1 x 1 deg) were alternately presented with no ISI. The diameter of the arrays was 7 deg. The alternation rate was varied in 5 steps between 1.67 and 5.00 Hz. Participants were asked to track one object (target) for 1.8 sec. The maximum temporal rate was defined as the rate that corresponds to 75% correct responses. It was found that the upper temporal limit was approximately 4 Hz in within-attribute conditions regardless of attributes. The cross-attribute conditions yielded much lower limits. It was about 2-3 Hz irrespective of attributes paired to luminance. These results indicate that, (1) the 4-8 Hz limit is specific to tracking with objects defined by single attribute, (2) this limit is not affected by attribute types including first- and second-order difference, and (3) cross-attribute trackings involve a much slower higher process than that for within-attribute trackings. There seems two separate types of object trackings; one for within-attribute, and the other for cross-attribute trackings.

23.435 **Automatic feature-based grouping during multiple object tracking**

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Purpose: Prior studies (Keane, Mettler, Tsoi, & Kellman, 2010) have shown that the features of targets and distractors can be utilized to form illusory contours during multiple object tracking. When contours connect targets,

tracking improves; when contours connect targets and distractors, performance worsens. Can features besides those that elicit interpolation also lead to automatic grouping? Method: Displays contained four pairs of objects, one pair in each quadrant. Observers tracked one target in each pair. We examined grouping in the context of seven additional potential grouping factors: color, contrast polarity, orientation, size, shape, stereoscopic depth, and a combination (size+shape+color). Displays were created using two feature values of each grouping factor (e.g., red and green for color). All objects were identical at target designation and at response; distinctive features were only visible during the motion phase. There were two conditions in Experiment 1. For the target-group (TG) condition, all targets had one feature (e.g., red) and all distractors had the remaining feature (e.g., green). For the target-distractor group (TDG) condition, half the targets and half the distractors had one feature and the remaining objects had the other feature. In Experiment 2, we compared the TDG to a No-group baseline condition in which all objects were identical at each moment. Results: In Experiment 1, the TG condition was better than the TDG condition for all grouping factors (all $p < 0.001$) except orientation. In Experiment 2, performance in the TDG condition was worse than the No-group condition for all grouping factors (all $p < 0.005$) except for orientation, depth, and contrast polarity. Conclusion: Observers used grouping factors in both experiments even though they were not instructed to. In Experiment 2, they used grouping factors even though it hurt their performance. In addition to interpolation, color, size and shape can lead to automatic grouping during attentional tracking.

23.436 Trained Older Observers Are Equivalent To Untrained Young Adults For 3d Multiple-object-tracking Speed Thresholds

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There is ample evidence that the normal aging process affects visual perceptual processing. This is particularly true when images or scenes are more complex (Faubert, 2002). For instance, it has been demonstrated that older observers are less sensitive to higher-order visual information (Habak & Faubert, 2000; Herbert et al., 2002). A perceptual-cognitive task of particular relevance is multiple object tracking or MOT (Pylyshyn, 1989), which has been shown to be less efficient with aging (Sekuler et al., 2008; Trick et al., 2005). MOT is a task where the observer is required to simultaneously track multiple elements among many and the ability of the observer is evaluated by the number of elements that the observer can track without making a mistake. A question remains as to whether older observers can be trained to regain this age-related loss. Such regain has been demonstrated for other visual perceptual tasks such as the "useful field of view" a technique that requires dual processing (Richards et al., 2006). We evaluated the performance of older and younger observers (speed thresholds) in a 3D virtual environment and demonstrated that indeed older observers were less efficient at MOT. However, after several weeks of training, the older group performed as well as the untrained younger group. This is encouraging given that most of us are required to process multiple moving elements in our real world (e.g. tracking people in crowds, sports, driving, etc.). Our results in conjunction with other studies demonstrates that the older brain remains plastic and training is a viable option for regaining certain perceptual-cognitive abilities that were lost by the normal aging process. Regaining such capacities may have an impact on individual confidence in performing daily activities and may consequently improve their general quality of life.

23.437 Asymmetric attention foci during multiple object tracking: Evidence from distractor displacements

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Several activities such as driving or video-gaming require the ability to track several objects simultaneously. This ability is studied in the multiple object tracking paradigm (MOT). Observers track targets among identical distractors. Previous research suggests that distractors are inhibited during MOT by narrowing the attention foci on targets to compensate decreasing target-distractor distances. In four experiments, we tested whether the sizes of the attention foci are dependent solely on inter-object spacing and thus symmetrical around targets or whether they omit distractor locations. During brief flashes, we displaced each distractor on a circular path around

its associated target object thus maintaining inter-object spacing. Distractor displacements would not impair tracking performance if the attention foci were symmetrical around targets whereas displacements would decrease performance if the attention foci were asymmetric around targets. In Experiment 1a, we observed impaired tracking performance when distractors were displaced during tracking. Changing movement directions of distractors improved performance. Experiment 1b revealed direction changes of distractors to increase performance only when they are unique for distractors, whereas target direction changes impaired tracking in general. Furthermore, we tested whether changes in the global (Experiment 2) or local configuration (Experiment 3) of objects can account for the effect of distractor displacements. In Experiment 2, we varied the number of displaced distractors. We observed tracking performance declining linearly. In Experiment 3, we controlled for local configuration changes. During each trial, three distractors were displaced by 50°, 100°, or 150° around their associated target. One distractor was not displaced. Tracking was less accurate with larger displacements. However, for 50° displacements performance was equal to no displacements. We conclude that the attention foci omit distractor positions and that attention is not symmetrically distributed around targets. We argue in favor of a flexible resource model deploying attention asymmetrically among and around tracked targets.

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23.438 Quantification of the self-motion load on multiple object tracking: How many objects are you worth?

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Perhaps walking and chewing gum is effortless, but walking and tracking moving objects is not. Keeping track of moving targets among moving distractors is impaired by walking from one location to another, suggesting that updating location of the self puts demands on object tracking processes (Thomas & Seiffert, 2010, Cognition). Here, we quantified the cost of self-motion in terms of the tracking load. Participants in a virtual environment tracked a variable number of targets (1-5) among distractors while either staying in one place or moving along a path that was similar to the objects' motion. At the end of each trial, participants decided whether a probed dot was a target or distractor. As in our previous work, self-motion significantly impaired performance in tracking multiple targets ($F(4,52)=39$, $p < .001$). Accuracy of tracking 3 targets while moving (86% correct) was similar to tracking 4 targets while staying (85%, $t < 1$, ns), but significantly better than tracking 4 targets while moving (79%, $t(13)=3.7$, $p < .005$) which was similar to tracking 5 targets while staying (81%, $t < 1$, ns). Quantifying tracking capacity (K) under the two conditions and fitting the results to an asymptote revealed that self-motion during tracking produced a cost to capacity of about 0.8 objects. Tracking your own motion is worth a little less than one object, suggesting that updating the location of the self is similar, but slightly easier, than updating locations of objects.

23.439 Misrepresentation of motion direction causes prediction errors in multiple object tracking

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Do people use local motion information to predict the future locations of targets during multiple object tracking? Our previous research suggested this may be true because tracking accuracy was lower when the motion of texture on the targets conflicted with the motion of the targets themselves compared to when it did not (St. Clair, Huff, & Seiffert, 2010, JOV). However, these findings allowed for the possibility that it was the perception of object position and not object motion that was affected by the texture motion. Here, we investigated whether the motion direction is misrepresented for objects with conflicting texture motion. Observers tracked 3 of 10 dots that moved independently and linearly in a box filled with random-dot texture. The dots were either grey or filled with a random-dot texture that moved at 2 times the dot speed in either in the same direction, the opposite direction, or orthogonal to each dot's trajectory. At the end of the tracking period, observers used the mouse to adjust the orientation of a line to match the direction of motion of a randomly-chosen target. The mean absolute error was lower for grey targets (38°) and targets with same-moving textures (35°) than for opposite-moving textures (56°; $t(12) = 4.58$, $p < 0.01$) and orthogonal-moving textures (59°; $t(12) = 4.60$, $p < 0.01$). These

findings are consistent with our hypothesis that people misrepresent the direction of objects with conflicting texture motion. The misrepresentation of direction causes inappropriate predictions of future target locations that result in tracking errors.

23.440 Expanding Attentional Capacity with Adaptive Training on a Multiple Object Tracking Task

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One frequently used task for measuring attentional capacity is multiple object tracking (MOT), where observers attentively track multiple moving target items among a set of identical distractors. MOT performance depends on both the number of targets and their speed (Alvarez & Franconeri, 2007), and therefore provides two measures of attentional capacity: (1) the number of items that can be tracked at a fixed speed, (2) the maximum speed at which a fixed number of items can be tracked. Previously, we showed that 10 days of adaptive MOT training increased performance on both of these measures. Here, we replicate these results, then extend them with the inclusion of (1) an active control group, (2) pre-training and post-training structural and functional neuroimaging measures, and (3) an extensive battery of normed "transfer" tasks, to determine whether improvement in visual attention affects other cognitive domains. Initially, a threshold procedure was used to determine the speed at which subjects could track four targets among twelve distractors. Subjects then completed twenty sessions of MOT practice (90 trials per day), with the object speed on each trial adaptively updated based on the current trial's performance. Over twenty sessions of training, eight subjects increased the speed at which they could reliably track four objects from an initial average of 5.5 deg/s to a final speed of 13.1 deg/s. Additionally, all subjects were able to track additional targets when tested at their initial pre-training speed. In contrast, subjects assigned to the "active control" condition (an adaptive n-back task) did not significantly improve on these MOT metrics. These findings confirm that it is possible to dramatically increase the capacity of visual attention through training, and that training one measure of capacity (increased tracking speed) transfers improvements to a second measure of capacity (increased number of targets).

23.441 iMOT: interactive Multiple Object Tracking

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We introduce a novel, iPad-based experimental paradigm to study interactive multiple object tracking (MOT). In standard MOT, participants passively track a set of independently moving objects. We devised a new task in which participants interact with objects, rather than simply track them. We combined a typical MOT display with the path-guidance, touch-screen interface popularised in smart phone games such as Flight Controller and Harbor Master. We ran the experiment using a custom iPad application. A variable number of identical spheres (1.16° visual angle) moved slowly (0.89°/s) on independent linear trajectories within the full iPad display area (22.6° x 17°). Random direction changes occurred at intervals between 4 and 7 s. The participant's goal was to avoid object collisions by manually altering the sphere trajectories. This was achieved by touching the sphere and drawing a short linear or curved path away from it. This action created a visible path, which the sphere followed before resuming default random motion. In this initial study, we constrained path length, in order to prevent participants from creating complex "holding patterns". A trial ended when the participant successfully avoided collisions for 30 s or when a collision occurred. A sphere was added to the display after a successful trial and removed after a collision, subject to a 6-sphere minimum. Twenty-four participants (ages 18 to 33, mean 23.58, sd 3.45); twelve from Korea University, twelve from Swansea University) completed 30 trials. There were no significant effects of culture, sex or previous gaming experience. The mean number of spheres participants could control was 8.39 (s.e.m. 0.14). This is consistent with estimates of passive tracking capacity at slow speeds. We

hypothesize that executive control of scant attentional resources is critical for the current task. In support of this hypothesis, interactive tracking capacity actually increased with age ($p = .016$).

Visual memory: Encoding and retrieval

Saturday, May 7, 8:15 am - 12:15 pm

Orchid Ballroom, Poster Boards 442 - 457

23.442 Individual Differences in Visual Cognitive Abilities

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Individual differences in visual cognitive abilities have been shown to correlate with a variety of important real-world outcomes, such as performance on standardized aptitude tests. Recent research has explored the possibility that various training paradigms can enhance visual cognitive abilities. Of principal interest is whether these interventions will increase other more distant outcome measures, such as performance on standardized tests or in the classroom. As interest in this area is growing, it is increasingly important to develop normed, standardized laboratory tasks that can be used to assess the development of visual cognitive abilities. We have developed such a task battery, which includes measures of visual attention, visual working memory, verbal working memory, and mental rotation ability. Each task requires approximately 8 minutes to administer, and was found to be highly reliable (test-retest reliability ranging from $r=.8$ to $.9$), and highly independent of each other (across task correlations less than $r=.35$ for all pairs of tasks). We have deployed these tasks in field experiments, testing whether an educational intervention affects visual cognitive abilities. Specifically, we are investigating whether doing math with a mental abacus will enhance visual memory, visual attention, and mental rotation ability, but not verbal memory ability. 200 students at the Zenith school in Gujarat India have been randomly assigned to learn to do math with a mental abacus, or to receive additional standard math education. Thus far we have established baseline ability levels for these two groups, which do not differ on any individual task. In follow up studies (March 2011, 2012) we will assess whether mental abacus training affects visual cognitive abilities and classroom performance.

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23.443 Effects of updating visuo-spatial working memory in early visual cortex

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Visuo-spatial working memory refers to the ability to actively maintain a spatial representation of visual information in order to interact with it. Although supported by a network of frontal and parietal structures, it is hypothesized that storing spatial information relies heavily on visual cortex. Indeed, due to its retinotopical lay-out, visual cortex appears to be an ideal candidate for storing location-specific information. In the current study we investigated whether updating the contents of visuo-spatial working memory (in the absence of visual stimulation) is accompanied by changes in activation in visual cortex. Participants were instructed to remember the exact locations of four presented images. After the images were removed from the screen, participants received a central cue (a word, describing one of the images) that told them to keep only one of the locations in memory. After a retention period a marker would appear and participants had to indicate whether the marker was presented at the exact location of the memorized image. On a number of trials a second cue-word describing one of the other images was presented during the retention period, informing the participants that they had to remember, and would be tested on the location of the image indicated by this word. This resulted in an update of the contents of spatial working memory. BOLD responses were measured during the retention period on each trial. The results show that visual cortex is modulated by spatial working memory in the absence of visual stimulation. Furthermore, updating the contents of spatial working memory leads to retinotopically specific changes in activation in early visual cortex. These results suggest that visual cortex is pivotal for maintaining and updating spatial working memory representations.

23.444 Spike count correlations between primate dorsolateral prefrontal cortex neurons during a spatial working memory task

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It has been shown that neurons in the primate prefrontal cortex encode information during the delay period of working memory tasks for spatial locations, however it remains unclear whether and how these units interact with each other. We examined this question by recording single cell responses from microelectrode arrays (each array = 96 microelectrodes, Blackrock Inc., UT) implanted in dorsolateral prefrontal cortex (area 8v) of two macaca fascicularis during a working memory task, and measuring spike count correlations between the recorded units. During trials the animals fixated on a central spot for 494 to 800ms, then a circular sine wave grating was presented at one of 16 randomly selected locations for 507ms. The offset of the grating was followed by a delay period that could last between 494 and 2000ms and ended with the offset of the central fixation point. This latter event instructed the animals to make a saccade to the remembered location of the previously presented grating. The spiking activity of neurons was simultaneously recorded in blocks of 32 channels and sorted using Plexon software (Plexon Inc, TX). We recorded from 20 well isolated single units for a total of 190 neuronal pairs. We found that spike rate correlations between the pairs computed across all target locations were significantly higher during the delay period ($r = 0.13$) than during the stimulus presentation period ($r = 0.04$) ($p < 0.01$, paired t-test). Our results suggest that interactions between neurons in the dlPFC increase during working memory maintenance in the absence of visual inputs. Such interactions may be critical for working memory encoding by neuronal populations within the area.

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23.445 Short-term visual recall is preserved in aging

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Normal aging brings diminished performance on many cognitive tasks. However, some recent studies suggest that visual short-term recognition memory is preserved (Sekuler et al. 2005). To test the boundaries of such preservation, we exploited direct-matching recall, which is sensitive to subtle imperfections in visual memory (Huang & Sekuler, 2010). In this task, subjects adjust one stimulus to match the remembered characteristics of another.

Methods. On each trial, subjects saw two Gabors (each 500 msec) presented in rapid succession. Subjects reproduced the remembered spatial frequency of either the first or the second Gabor. We manipulated the usefulness of attentional selectivity by presenting a cue either before both stimuli (pre-cue) or after (post-cue) in a block design. The cue specified which Gabor, first or second, subjects should match. The presentation of a pre-cue made one upcoming stimulus task-irrelevant, enabling subjects to encode and store only the other stimulus. Subjects were 10 younger (18–24 years, $M = 22.1$) and 10 older (62–76 years, $M = 68.5$) adults.

Results. (1) Older subjects' accuracy in memory-based matches was equal to that of the younger subjects. (2) The two groups of subjects showed substantial and equal improvement in accuracy when a pre-cue allowed them to selectively attend to just one of the two stimuli. (3) Subjects in both age groups exhibited a Prototype effect: reproduced frequencies were shifted toward the prototypical value of stimuli seen on previous trials. (4) This Prototype effect gained strength when subjects had to encode and remember two, not one stimulus. This last result is consistent with the hypothesis that the Prototype effect reflects an adaptive augmentation of an imprecise memory.

Short-term recall is preserved with aging, as are the benefits gained from selective visual attention. Both outcomes suggest the importance of compensatory changes in cortical circuitry (McIntosh et al, 1999).

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23.446 Training Improves Stability of VWM Representations

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In order to prevent visual representations in visual working memory (VWM) from being overwritten by subsequent visual information, some process must stabilize the activated representations so that they are less susceptible to interference. This process is called short-term consolidation (Jolicoeur & Dell'Acqua, 1998; Vogel et al., 2006). The current study examined this process, specifically if training facilitated the stabilization of visual representations in working memory. Two experiments compared performance between trained and novel stimuli using the backward masking paradigm. In the backward masking paradigm, visual masks are presented at varying intervals following a memory and participants make a same/different judgment when presented with the test array. Additionally, the set size of the visual array was manipulated to examine how the impact of the visual masks varied depending on how many items there were in the array. In Experiment 1, participants trained on a set of random polygons using a four alternative forced choice task. An advantage was found for trained items in accuracy and capacity as well as faster consolidation for trained items. Additionally, there was no interaction between set size and delay for trained items, suggesting that participants were able to consolidate the array as a single unit instead of requiring more time for more items. In Experiment 2, participants trained using a change detection task and no differences were demonstrated between trained and untrained items, including no interaction between set size and delay for either stimulus type, suggesting transfer of change detection training to novel stimuli. Taken together, these results show that (1) long-term visual representations play an early role in VWM by stabilizing visual representations; (2) short-term consolidation is a multidimensional process that involves visual and spatial properties; and (3) training of visual stimuli may transfer to novel stimuli depending on the type of training.

23.447 Retrieval-induced Perceptual Suppression: Selective retrieval of mental images can result in perceptual deterioration of non-retrieved images

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An attempt to retrieve an item from memory can result in negative effect on future retrieval of other related-but-unwanted items, and such negative consequence of selective retrieval is called 'Retrieval Induced Forgetting' (Anderson, Bjork & Bjork, 1994). The majority of research on retrieval-induced forgetting has employed word recall task to demonstrate the suppression of non-retrieved items on semantic level. The current study suggests that selective retrieval during mental imagery can invoke deterioration of perceptual representation itself. The participants engaged in mental imagery task in which they retrieved the shape of previously studied line-drawing pictures in mind. The category name and the fragmented lines of each picture were presented as retrieval cues. Experiment 1 measured recall accuracy for the picture names to determine whether mental imagery task can invoke retrieval-induced forgetting in verbal dimension. The result showed that recall accuracy for non-retrieved items in retrieved categories (Rp-) was significantly worse than that for non-retrieved categories (Nrp). Experiment 2 employed perceptual identification task in which participant adjusted the level of occluding noise until they were able to identify the original pictures. Noise level for correct identification was lower for Rp- items than Nrp items when measured with the identical pictures presented at the study phase but not with mirror-reversed pictures. This result confirms the decline in identification performance for Rp- items was mainly due to perceptual suppression than to semantic suppression. Experiment 3 employed recognition between a pair of different pictures that have the same name and meaning. The result showed that recognition time for Rp- items was slower than Nrp items. These results suggest that selective retrieval of specific representation during mental imagery can induce forgetting of semantically related-but-unwanted representations in perceptual dimension.

23.448 Resolution of Representations in Spatially Cued Attention and Visual Working Memory: A Multi-Alternative Perceptual Template Decision Model

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Attention can improve the accuracy of visual discrimination, however little is known about how attention affects the precision of visual encoding and the implications for subsequent visual working memory (VWM). Four randomly oriented Gabors were displayed briefly. Encoded representations of a target Gabor were assessed through report of a feature – here, orientation – by choosing from a 20-orientation palette, one every 9° (-90° to 90° = -90°). In a spatial attention condition (Chu, Doshier, & Lu, VSS 2010), the target Gabor was marked with a simultaneous report cue and attention was either validly or invalidly pre-cued. We report two new VWM conditions with a report cue 900 ms after the four-item display. One VWM condition included an attention pre-cue, and a standard VWM condition did not. Performance in all three conditions showed considerable variability in the probability of reporting the correct, or very close, target orientation(s) yet showed remarkable stability in the spread about the correct orientation. Probability of reporting the target increased with contrast, decreased with external noise, increased with valid pre-cuing, and decreased with delay. There was little evidence for intrusions from non-target locations. The surprising similarity of the spread about the correct orientation over conditions together with many other detailed features of the complex data pattern were well accounted for by a multi-alternative perceptual template model of the observer. Twenty templates respond to the target stimulus with gains determined by the degree of match and the contrast, and noise variance determined by both internal and external noises. The reported orientation is selected by a max rule. The stable clustering or precision of reported orientations reflects the tuning of the templates, which are estimated as closely similar to the matched-template. The data, and the corresponding model, suggest a common mechanism for immediate perception and visual working memory.

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23.449 Efficient Detection of a Supra-threshold Change Revealed by Pattern-backward Masking

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Detection of a supra-threshold change has been reported to be very fast and accurate, and thus the comparison between memory and perceptual representations seems to occur very rapidly in an automatic fashion (Hyun et al., 2009). To explore further the nature of the comparison process, we used a visual masking paradigm in which complex pattern masks followed test items that are compared against remembered items in visual working memory. We also aimed to contrast the time course of this comparison process against the time course of visual working memory consolidation which is known to be relatively time consuming compared to simple feature pop-out detection (Vogel, Woodman & Luck, 2006). In Experiment 1, subjects performed a color change detection task in which complex pattern masks followed either sample (sample-mask condition) or test items (test-mask condition) made of four-colored boxes, and the mask onset asynchrony (MSOA) in the sample-mask and test-mask conditions were varied to either 64ms or 150ms. Subjects' change detection performance was greatly impaired in the sample-mask condition for both 64ms and 150ms MSOA condition. However, in the test-mask condition, the performance for the 150ms condition was much accurate compared to the performance for the 64ms MSOA condition. In Experiment 2, we further manipulated display setsize from 1 to 4 and varied MSOA by 117, 234, 350, 584ms. In the sample-mask condition, as the MSOA became shorter, increasing display setsize led to a stronger masking effect whereas the masking effect diminished in the test-masking condition. The results indicate that comparison between memory items and perceptual inputs is less vulnerable to interference from pattern-backward masking than VWM consolidation is, and support for the idea that detection of a visual change can be as efficient as detection of a pop-out feature in visual search.

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23.450 The neural processes underlying memory encoding and retrieval of own-race and other-race faces

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People are generally better at recognizing faces from their own race than from a different race. The so-called other-race effect has been examined in numerous behavioral studies, but its underlying neural processes have been less extensively researched. This study investigated how differences between own-race and other-race faces influence memory encoding and recognition memory. Event-related potentials (ERPs) of Asian and Caucasian participants were recorded during the study and test phases of a Remember-Know paradigm with Asian and Caucasian faces. The other-race effect was apparent in both groups, neither of which recognized other-race faces as well as own-race faces; but Caucasian subjects showed stronger other-race effects in memory performance. Using ERPs, we independently investigated the influence of stimulus race on two time points of memory: encoding and recollection. In the study phase, memory encoding was measured with mean amplitudes and the ERP difference due to memory (Dm). Correctly "recollected," own-race faces elicited lower mean amplitudes and were thus more efficiently encoded into memory than correctly "recollected" other-race faces. Dms for subsequent recollection and familiarity were indistinguishable only for own-race faces, which suggest that more elaborate memory encoding occurred for own-race than other-race faces. Experience with a race also influenced old/new effects, ERP correlates of recollection measured during recognition testing, but only for Caucasian subjects. Own-race faces elicited a typical parietal old/new effect, whereas old/new effects for other-race faces were dominated by activity in frontal brain regions, suggesting a stronger involvement of cognitive control processes. The temporal dynamics of memory retrieval were also influenced by the race of a face. Whereas recognition of other-race faces was prolonged until at least 1200 ms and required post-retrieval monitoring, recollection of own-race faces was completed after about 900 ms. These results indicate that the other-race effect is a memory encoding- and recognition-based phenomenon.

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23.451 Visual search for a feature-absence target among to-be-remembered items can compete for attentional resources for VWM consolidation

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Forming a durable representation in visual working memory (VWM) requires a relatively time-consuming memory consolidation process, and thus may require involvement of an attentive process. In the present study, we tested whether or not change detection performance can be impaired when a feature-absence target embedded in a sample array is sought after. In Experiment, subjects performed a color change detection task in which sample array was made up of 3 or 6 colored letters (e.g., Q and O). In the simple feature pop-out condition, a target was a letter, 'Q' while distracters were all 'O's for each trial block of setsize 3 or 6. In the feature-absence search condition, the target designation was reversed. In each trial, subjects were asked to report target presence or absence as quickly as possible upon the sample array, and were asked to report presence or absence of a change when a test probe showed up after a memory delay. In the pop-out search condition, search RTs did not differ across the set size 3 and 6 trials, and change detection accuracy in the setsize 3 trials was higher than setsize 6 trials. In the feature-absence search condition, search RTs were slower in the setsize 6 than setsize 3 trials. Change detection accuracy in the setsize 6 trials was lower than the setsize 3 trials just like as in the pop-out search condition, but the difference of the accuracy was more evident than that in the pop-out search condition. The results indicate that searching for a feature-absence target embedded in the sample array competes for attentional

resources during consolidation of the sample items into VWM, whereas searching for a pop-out target does not evoke such competition. This supports for the idea that attention plays an important role when memory items are consolidated into VWM.

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23.452 Visual short term memory also gates long term memory without explicit retrieval

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The classic “modal model” of memory argues that short term memory (STM) serves as the primary gateway for the formation of long term memory (LTM) representations (Atkinson & Shiffrin, 1968). Over the years, though, this model has been disregarded by many because of various incompatible results. For example, one common interpretation of this model is that STM serves as an “incubator” that strengthens representations through repeated rehearsal so that they can be successfully transferred to LTM. However, several researchers have found that longer periods of retention and rehearsal in STM does not lead to better LTM representations (e.g. Craik & Watkins, 1973). In the past series of study, we took a different perspective to test this model. That is, rather than conceptualizing STM as an incubator, we instead tested whether it serves as the “gate” that filters what information from the environment will ultimately be encoded into LTM. Indeed, we successfully demonstrated that individuals with larger STM stored more LTM than those with smaller STM (Fukuda & Vogel, 2010) when their LTM was explicitly retrieved (e.g. recognition test). In the current research, we attempted to generalize this perspective even for LTM that is not explicitly retrievable. Here we found, (1) higher STM capacity individuals show better LTM performance than lower capacity individuals even when they do not indicate explicit retrieval (i.e. when they indicate that they are “randomly guessing”), and (2) higher STM capacity individuals show faster and better implicit learning for spatial context (i.e. contextual cueing). These results further strengthen the generalizability of “gateway” perspective of STM for the formation of LTM.

23.453 The capacity of encoding into visual short-term memory

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Goal: Many everyday activities depend on our ability to construct, maintain, and compare representations in a constantly changing visual environment. This ability has been shown to rely on a form of memory known as visual short-term memory (VSTM). Although considerable research has examined the capacity limits of short-term memory stores, few studies have addressed the initial formation of VSTM representations. Here we used a sequential-simultaneous task that allowed us to investigate limits in the process of initially encoding items into VSTM. Methods: Participants were shown colored objects (targets) presented briefly and followed by pattern masks. The target objects were shown either sequentially or simultaneously. A probe object followed the targets and participants decided whether it matched one of the targets in color (delayed match-to-sample test). In Experiment 1, we tested two targets on each trial and in Experiment 2 we varied the number of targets (either two, three, or four targets) across trials. In each experiment we measured the accuracy of participants' delayed match-to-sample performance. Results and conclusion: We consistently found equal performance for sequential and simultaneous presentations for two targets. Worse performance in the simultaneous than the sequential condition was observed for larger set sizes (three and four). These results indicate that encoding into VSTM is limited to two items, suggesting that only a subset of possible sensory representations are encoded concurrently. These results also suggest that one can selectively attend to more than one item at a time.

23.454 Electrophysiological Measures of Visual Grouping on Working Memory Representations

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The cognitive ability to group information into “chunks” is a well known phenomenon in verbal working memory paradigms. However, the effects of chunking within visual memory are not well understood. Previously, we have demonstrated how the bottom-up Gestalt principle of good continuation affects the “online” memory representations for elements in Kanizsa

figures. We have further demonstrated the effects of common fate or connectedness on the online representation of items during a Multiple Object Tracking task. Here, we investigate how learned arbitrary relationships between items in a visual display may be used to group the items, in the absence of bottom-up grouping cues. To do this, subjects learned patterns of dots related by color set, locations or both color set and locations, indicating the appropriate category for each novel exemplar. Following the learning of the stimuli, the subjects performed a color change detection task using the learned stimuli. ERPs were recorded during the experiment, in particular, we measured the contralateral delay activity. The amplitude of this ERP component is sensitive to the number of items being held in visual working memory. We were able to demonstrate an effect of the learning of color and pattern categories both on behavior and online memory representations during learning, as well as during subsequent performance of a change detection task using the learned stimuli. These results are relevant to our understanding of the representation of visual information and the effects of recently learned information on the encoding and maintenance of information online.

23.455 Multiple Spatial Frequency Channels in Human Visual Perceptual Memory

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Current models of short-term visual perceptual memory invoke mechanisms that are closely allied to low-level perceptual discrimination processes. The purpose of this study was to investigate the extent to which human visual perceptual memory for spatial frequency is based upon multiple, spatially tuned channels similar to those found in the earliest stages of visual processing. We measured how performance in a delayed spatial frequency discrimination paradigm was affected by the introduction of interfering or ‘memory masking’ stimuli of variable spatial frequencies during the delay period. Masking stimuli induced shifts in the point of subjective equality (PSE) when their spatial frequency was within a bandwidth of 1.2 octaves of the reference spatial frequency. When mask spatial frequencies differed by more than this value, there was no change in the PSEs from baseline levels. This selective pattern of masking was observed for different spatial frequencies and demonstrates the existence of multiple, spatially tuned mechanisms in visual perceptual memory. Masking effects were also found to occur for horizontal separations of up to 6° of visual angle between the masking and test stimuli. These findings add further support to the view that low-level sensory processing mechanisms form the basis for the retention of spatial frequency information in perceptual memory. However, the broad range of transfer of memory masking effects across spatial location indicates more long range, long duration interactions between spatial frequency channels that are likely to rely on contributions from neural processes located in higher visual areas.

23.456 Learning statistical regularities can speed the encoding of information into working memory

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Observers automatically learn statistical regularities in their environment, and use these regularities to form more efficient working memory representations (Brady, Konkle, Alvarez, 2009). For instance, when colors are more likely to appear in certain pairs (e.g., red with blue), observers learn these regularities and over the course of learning are able to remember nearly twice as many colors. Here we investigated whether the benefits of learning hold only at the level of memory storage, or whether perceptual encoding of learned pairs becomes more efficient as well.

During the learning phase, 8 colors were presented (four bi-colored objects). After a delay, one location was cued with a thick black outline, and observers reported the color that was presented at the cued location. The colors were paired such that 80% of the time certain colors co-occurred (e.g., red with blue). Over the course of 9 blocks of 60 trials, the number of colors observers could remember doubled from 3 to 6, indicating that observers learned the regularities and formed more efficient memory representations. Next, participants completed a rapid perception task. On each trial, a single color pair was briefly presented, followed by a mask, and then participants reported both colors. At brief presentation times performance was near chance. As time increased there was a reliable advantage for high probab-

ity color pairs over low probability color pairs (~15% accuracy difference at 67ms, $p < .05$). This difference cannot be explained by differences in storage capacity for high and low probability pairs, because only 2 colors had to be remembered, and there was no difference between conditions at the longest presentation times.

Such an encoding-time advantage for high-probability color pairs suggests that participants may actually perceive high probability color pairs more rapidly, and that the compression of learned regularities can influence low levels of perceptual processing.

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23.457 Two Object Subliminal Priming

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Previous research has investigated the extent to which visual images of objects that are not consciously perceived are processed. To this end, Bar and Beiderman (1998), using a subliminal priming paradigm found that sub-threshold presentations of single objects do indeed affect performance on subsequent tasks. We asked if two sub-threshold objects would both affect future performance, a question we think has never been answered. We created a paradigm in which two black and white line drawings representing familiar objects and subtending approximately 3.5 degrees, positioned 3.5 degrees to the left and right of fixation, were presented for 14ms and pattern masked. Subjects were then presented with two test items which they had to identify as either the same or different from one another. One of the previously presented primes was always used as a test item. Forty subjects were tested and each subject participated in 200 trials. We reasoned that if the subliminally exposed objects were processed outside of awareness, then subjects' responses to the same-different task would be quicker than their responses on trials in which no prime was presented. We found that this was the case; reaction times on primed trials were significantly shorter than those on trials in which subjects were not exposed to primes (same condition $p = .011$; different condition $p = .000$). We understand our results to represent the first demonstration of subliminal visual priming of more than one object.

Motion: Biological motion

Saturday, May 7, 8:15 am - 12:15 pm

Vista Ballroom, Poster Boards 501 - 518

23.501 The perception of animacy in humans and squirrel monkeys (*Saimiri sciureus*)

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The purpose of this study is to examine the influence on the perception of animacy of visual motion cues or information. The study focuses on the preference in predatory activity of squirrel monkeys on the basis of whether their baits or feeds are alive or dead. In experiment 1a, two mealworms (one alive and the other dead) were simultaneously placed in front of the monkeys to investigate whether they could discriminate between the alive and dead mealworms based on whether they are moving or not. We introduced a mechanical rotary movement to see if the monkeys could distinguish a natural movement of living matter from the artificial rotary movement. The monkeys showed a preference for the live mealworms over the dead ones, suggesting that the mechanical motion did not influence the predatory activity of the monkeys. In experiment 1b, taking into consideration the possibility of the monkeys discriminating between the alive and dead mealworms, using other cues than the motion information used in experiment 1a, we introduced differences in constant brightness, shape, and placement among the stimuli. Thus, the monkeys were completely forced to choose the mealworms, using only the motion cues. The results we obtained are similar to those obtained in experiment 1a, indicating that the monkeys perceived animacy from the motion cues. In experiment 2, we presented moving images of similar stimuli to human subjects under the same conditions as those used for experiments 1a and 1b, and asked human subjects to select that one of the images which gave a stronger impression in terms of biological features. The result of this experiment suggested that motion information mediates animacy perception in common to squirrel monkeys and humans.

23.502 Integration of form and motion for biological motion displays in the monkey

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fMRI experiments in the human using point-light animations have shown that the extrastriate and the fusiform body area are involved in the integration of form and motion features of biological motion (Jastorff & Orban, 2009). Using the same design as in our previous study, we performed fMRI experiments in awake monkeys to investigate whether monkeys would be sensitive to point-light animations, and if the body areas in the monkey would play a similar role as the ones in the human. The point-light stimuli consisted of sixteen white dots indicating the position of the head, the major joints of the limbs and the tail of macaque monkeys performing different actions like running, jumping and climbing. In a 2x2 factorial design, one factor manipulated the configuration of the stimuli by spatially randomizing the starting position of each dot. The second one modified the kinematics of the stimuli by changing the trajectory of each dot to simple translation. In addition, we identified body areas and retinotopic areas in separate localizer runs. The body localizer points to two main body areas, one anterior to FST, the other one located on the lower bank of the anterior STS (Popivanov et al. 2010). Similar to the human results, we obtained a significant superposition of both main effects and thus strongest activation for intact point-light monkeys, when using the independently defined body areas as regions of interest. Moreover, the main effect of kinematics elicited significant activation in the upper bank of the STS, possibly area STPm, and the one of configuration lead to activation in the lower bank and lip of STS up to the level of TEO. Our results indicate that monkey STS processes biological motion (Oram & Perrett, 1996) and that the principle of processing of complex actions seems very similar between humans and monkeys.

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23.503 How does the brain identify living things based on their motion?

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Identifying living moving things in the environment is a priority for animals, as these could be prey, enemies or mates. When the shape of the moving object is hard to see (fog, twilight, great distance, small animal), motion becomes an important cue to detect it. The neural correlates of the detection of an isolated living entity on the basis of its motion are largely unknown.

To study this phenomenon, we developed a single-dot stimulus, thus eliminating all possible sources of information about form, spatial arrangement, shape or structure of the object. The dot moved such that it appeared self-propelled, or moved by an external force, or something intermediary according to a small set of parameters. Self-propelled stimuli were perceived as more animate (= more likely to be alive) than the externally-moved stimuli, with a gradual transition occurring in the intermediary morphs following a classic psychometric function (cumulative gaussian).

In an fMRI experiment, 20 subjects had to categorize these stimuli into alive and non-alive. A region of the left medial posterior parietal cortex (mPPC) showed BOLD signal correlating with the probability of animacy judgments about the moving dot. While activation in parts of the early visual cortex showed the same response, the mPPC was the only region in which changes in percept had a stronger effect on activation than physical changes in the stimuli. In addition, only the mPPC showed BOLD signal increases when a stimulus was judged to be animate, irrespective of its physical characteristics.

This study shows that parts of the early visual cortex but particularly the medial posterior parietal cortex (mPPC) are involved in judging the animacy of an isolated translating visual stimulus, without information about its form.

23.504 A New Action Library for Localising Brain Activity Specific to Biological Motion

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Ahlstrom, Blake and Ahlstrom (1997) introduced a point-light stimuli set for the study biological motion perception. It consisted of 25 assorted actions sampled at 20 Hz for a 1 second duration and an additional 25 scrambled versions of the same actions. We revisited this stimulus set with an aim to examine the effects of using more rapid acquisition rates and obtaining higher quality data without missing markers. Using a 12 camera Vicon system we recorded the motions of an actor to obtain an equivalent set of 25 actions at a sampling rate of 120 Hz. These data were processed into movies of 1 second duration at a display rate of 60 Hz that showed black dots on a grey background. This display set was subsequently used in an fMRI experiment that contrasted brain activity when viewing the intact displays to brain activity when viewing the scrambled displays. This was achieved using a 3T Tim Trio scanner (Siemens) with a TR of 2000 msec and a block design. Each block had either all intact or all scrambled displays and a total duration of 16 sec, made up of eight 1-second animations followed by a 1-second blank screen. Analysis of the contrast between intact and scrambled blocks was examined for activity in posterior STS (pSTS), a region implicated in biological motion processing. Preliminary results from scanning the first 8 participants showed activity in the left pSTS for 2 of 8 participants and in the right pSTS for 4 of 8 participants. The lack of consistent activation in pSTS appears in contrast to results obtained in previous studies with the original displays. Possible theoretical reasons for this difference will be discussed.

23.505 Depth cues in point-light biological motion

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Non-profile views of point-light biological motion convey a clear impression of the direction in depth in which the actor faces. This is even the case if no explicit depth cues, such as disparity or perspective, are added to the display. We asked how well normal human subjects can judge the facing in depth of point-light walking. We found that subjects were quite proficient at this task. Minor errors consisted of hysteresis errors around the profile and frontal views, a systematic bias toward the profile view and variable errors. We then asked which cues are most important in the judgment of the facing direction. For this we employed five different manipulation on the point light stimuli: reversed (backward) walking, scrambling in time, scrambling in the phase of the joint-movements, scrambling in the phase of the point-movements (rubber-like), scrambling in spatial position. The facing in depth of these stimuli was increasingly difficult to judge, showing that different aspects of the point light motion contribute differently to the depth percept.

23.506 Before, During and After You Disappear: Aspects of timing and dynamic updating of the real-time action simulation of human motions

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When we see other people moving, we often see them briefly disappearing from view behind objects, or otherwise obscured from sight. Previous research shows that individuals generate real-time action simulations that aid the prediction of the future course of actions (Graf et al., 2007). Last year (Parkinson et al., VSS 2010) we showed that action simulations directly aid the perception of visually degraded human motions. Here we further investigated detailed aspects of timing in action simulation using newly developed versions of our occluder paradigm: A point light actor (PLA) representation of human motion performing a simple action, such as a basketball shot, was presented then briefly (500 ms) occluded from view, during which the participant's visuo-motor system automatically generated a real-time action simulation. Following the occlusion period, the PLA reappeared in motion as either a natural progression of the motion as it would have continued during occlusion (thus temporally congruent with

the action simulation), or shifted earlier or later in time. Participants judged whether the reappearing test motion was a correct or incorrect motion continuation, testing the accuracy of their action simulations.

We show that inserting just four frames (67 ms) of PLA motion within the occluder dynamically updates the action simulation, accordingly affecting subsequent motion judgements. Further, we show that the duration of motion presented before the occluder makes little difference to judgement accuracy, with accurate motion predictions made from remarkably little perceived motion (~50 ms). However, judgement accuracy is detrimentally affected by reducing the duration of the test motion (from 500 ms to 50 ms), suggesting that a certain minimum of visual motion information is required to compare to the internal action simulation. Thus we provide further evidence that action simulation is a dynamic, real-time process, remarkably adapted to making predictions about human biological motion from relatively impoverished information.

23.507 A test battery for assessing biological motion perception

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Tests designed to measure biological motion perception have often confounded two or more distinct perceptual abilities. These abilities include structure-from-nonrigid-motion, figure-ground segregation, and processing of local motion invariants. We have developed a battery of tests that measure these abilities independently, in addition to higher level biological motion abilities including action recognition, movement style perception, and person recognition. Seventy-five participants completed the battery, allowing for an individual-differences analysis. The lack of correlation between scores on the tests provides support for the independence of the underlying processes. In order to assess robustness of the tests to differences in the experimental environment, and to measure test-retest reliability, we had 30 additional participants complete the battery both in the lab and on their home computers. There was no effect of environment for the majority of the tests. Together, the results suggest that the test battery efficiently measures the components of biological motion perception, and performs nearly as well under uncontrolled viewing conditions. One future use of the battery is to fully characterize the perceptual deficits of special populations with respect to biological motion.

23.508 Structural Neural Correlates of Biological Motion Detection Ability

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Detection of biological motion is both commonplace and important. Humans vary considerably in their ability to detect biological motion but the neural correlates of these individual differences remain poorly understood. A network of brain areas (the action perception system or APS) including the posterior superior temporal sulcus (pSTS) is linked to biological motion processing. Here, we investigated neural substrates of individual differences in biological motion perception in a large group (n=31) of healthy individuals. We measured performance in several different psychophysical experiments hypothesizing that consistent individual differences across tasks would indicate joint mechanisms supporting these tasks. We also examined whether the anatomical structure of action perception regions was associated with biological motion detection ability using voxel-based morphometry (VBM). In a biological motion detection task, point-light animations depicting familiar actions were presented with a variable number of noise points, and detection thresholds were estimated adaptively. We also obtained thresholds for biological motion direction discrimination, non-biological object motion detection and direction discrimination, and motion coherence. Structural MRI scans were used to identify neural correlates of behavioral performance. Behaviorally, weak or absent correlations between individual differences in biological motion detection performance and other tasks suggested that different mechanisms may contribute to these abilities. These results can also explain some inconsistencies in the literature on biological motion processing. VBM analyses revealed that grey matter volume in the left pSTS was significantly associated with the ability to detect biological motion. This structural relationship was specific to

biological motion, because no correlation with pSTS gray matter volume was found for the other tasks, including direction discrimination task with biological motion stimuli. Furthermore, the left pSTS was the only region in the APS that predicted individual differences in biological motion detection performance. Our results delineate the structural neural basis of inter-individual variability in biological motion detection.

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23.509 Determining the feature sensitivity of visual areas to biological motion using brain-based reverse correlation

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Introduction. In recent work we have employed the spatio-temporal “bubbles” paradigm to investigate the diagnostic space-time features used by human observers and a computational model to discriminate biological motion patterns (Thurman, Giese & Grossman, 2010, *Journal of Vision*). Here we applied this paradigm to functional brain-imaging data to determine the space-time features of biological motion that drive high-amplitude BOLD responses in various visual regions of interest (ROIs). Methods. The bubble method samples the stimulus space randomly on each trial with a space-time mask, revealing portions of the stimulus through small Gaussian apertures. Reverse correlating brain responses with the bubble masks across many trials reveals the space-time features that drive the BOLD responses in those regions. In a targeted region of interest (ROI) analysis, we independently localized the following ROIs in each subject: posterior STS (biological vs. scrambled motion), EBA and FBA (static bodies vs. objects; see Downing et al., 2001, *Science*), and human MT+ (dot flow fields vs. static dots). Each subject then completed 20 “bubbles” scans in which 30 trials of masked point-light walking patterns were discriminated in a slow, event-related experimental design. We computed classification movies by reverse correlating the random “bubbles” masks with peak BOLD responses across all 600 trials for each subject (n=8) and each ROI individually. Maps were then combined across subjects and hemispheres to create group classification movies. Results. Despite the noise inherent to fMRI measurements, this method effectively yielded classification movies for each ROI. The classification movies across our targeted ROIs were highly correlated and revealed key features that were also apparent in the behavioral classification movie. In particular, dynamic features in the lower body that are critical for discriminating walking patterns behaviorally also appear to drive brain responses in this network.

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23.510 Neuronal Encoding of movement kinematics during action observation: a TMS study

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Several studies compellingly show that the human motor system is active during action observation. According to the direct-matching hypothesis this activation reflects a covert simulation of the observed action, possibly for the purpose of action or intention understanding. A prediction of this proposal is that the activation of the motor system during action observation should be modulated by the degree of similarity between the observed movement and those that can be actually produced by humans. We tested this prediction by measuring the excitability of the observer's motor system during the observation of human movements either complying or violating the 2/3 power law. The 2/3 power law is an empirical law stating that during curvilinear movements the instantaneous velocity of the end effector is related to the local curvature of the path by a power law with an exponent of two-thirds. Interestingly, it has been shown that, even after extensive training, humans cannot produce movements that violate this kinematic invariant. For our experiment, we first motion captured the movements of a human subject while he was moving his arms along curvilinear trajectories. We then animated computer characters with either the original movements or with a version of them that was manipulated so as to violate the 2/3 power law. On each trial, motor evoked potentials (MEPs) induced by single-pulse TMS were recorded simultaneously from the First right Dorsal Interosseus (FDI) and the right Extensor Digitorum Communis (EDC) while participants were passively observing videos showing the computer characters performing normal or distorted movements. Preliminary results

suggest that the amplitude of the MEPs, an indirect measure of the excitability of the observer's motor system, is modulated by the degree of compliance of the observed movements with the 2/3 power law.

23.511 Animated character appearance does not affect judgments of motion trajectory

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Animated characters abound in movies, games, and television. Their appeal depends not only on the roles portrayed by the characters, but also on their visual appearance and movement. There is a standard principle in computer animation that says that the visual complexity of the form of a character should match its motion and its environment (Lasseter 2001). Previous investigations of character form and motion have, to a certain extent, supported this principle. The perceived quality of motion is known to depend on the degree of human-likeness of a character (Hodgins et al. 1998, Chaminade et al. 2007, Reitsma et al. 2008). We wanted to test this principle systematically by varying the appearance complexity of animated figures and their environments and measuring the effects of these manipulations on aspects of motion perception. We presented five animated actors (point light figure, stick figure, box figure, a human-like and a ‘superhero’-like figure) jumping across a clearly marked distance. The jumps occurred in two contexts of different complexity: a high-quality rendering of two cliffs and a more basic, low-quality background of a tiled floor. All characters were animated with one set of motions that were captured from a single human actor. Observers (N=14) were shown the first half of the jump in context and asked to judge whether the character would clear the indicated distance on landing. Observers were able to predict the trajectory of the jump (83% accuracy, chance is 50%). However, there were no significant effects of manipulations of character form or environment. Our findings suggest that observers can extract information about motion in spite of large changes in appearance and context. Future work will examine the relationship between character form, motion and environment to determine how the measures (e.g., predicting trajectories vs. rating naturalness of motion) used to probe observers affect responses.

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23.512 Adapting to male or female faces induce gender aftereffect in point-light walkers

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Although drastically different in visual features, faces and point-light biological motions both convey important properties of human beings, such as gender. Gender seems specifically represented in either face or biological motion perception, as demonstrated by gender adaptation in both types of stimuli. However, whether there is a shared gender representation between them remains unclear. The current study probes this issue by examining whether adaptation to facial gender cues influences subsequent gender perception of biological motion signals. We found that prolonged viewing of a male or female face induced a gender aftereffect in a subsequently presented biological motion test stimuli. Viewing a male face made it more likely for a point-light walker to be perceived as female, and vice versa. This effect is unlikely a simple decision bias, as the magnitude of the aftereffect depended on the adaptation duration, a property consistent with traditional perceptual aftereffects. These findings suggest that there exists a common neural substrate for the gender representation of faces and biological motions.

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23.513 Bootstrapping a prior? Effects of experience on the facing bias in biological motion perception

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Perceptually bistable visual stimuli provide an interesting means to study how the visual system turns the generally ambiguous flow of sensory information into a reasonably stable model of the world. Biological motion point-light displays provide a particularly interesting class of stimuli in this

respect. Even though the stimulus itself does not contain any information about its orientation in depth, fronto-parallel projections of a point-light walker are preferentially seen as if the walker is facing the viewer rather than facing away. In two different experiments, we show that the degree of this “facing-the-viewer bias” strongly depends on the amount of exposure an observer previously had with point-light displays. We measure the degree of the facing bias by asking observers to indicate the apparent spin (clockwise or counter-clockwise) of a point-light walker – a method insensitive to a potentially confounding response bias. In the first experiment, we compared the degree of the facing bias between naïve observers and graduate students who work with point-light displays on a daily basis. In the second experiment, we exposed initially naïve observers over the course of several weeks systematically to point-light displays and measure the degree of the facing bias before and after this treatment. In both cases, we observe a substantial increase in facing bias with the amount of experience the observers had with point-light displays. We discuss these results in the context of a process which sharpens prior expectations by means of self-reinforcement in the absence of information that contradicts the developing prior.

Acknowledgement: NSERC

23.514 Footstep sounds increase sensitivity to point-light walking when visual cues are weak

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Multisensory neurons in superior colliculus display inverse effectiveness (IE); responses to multimodal stimuli are greater when the most effective unisensory stimulus produces a weak response (e.g. Meredith & Stein, 1983). Recently, fMRI evidence for inverse effectiveness has been found in superior temporal sulcus (Stevenson & James, 2009), a region implicated in multisensory integration (e.g. Barraclough et al., 2009) and human action perception (e.g. Blake & Shiffrar, 2008). While the relationship between neural IE and multisensory perception and performance remains unclear, and evidence suggests that not all multimodal processes adhere strictly to the IE rule (Holmes, 2007), behavioral studies have shown that the effect of auditory cues on visual processing is greater when the visual signal is relatively weak (e.g., Collignon et al., 2008).

Previously, we found that sensitivity to point-light walkers improves when paired with footstep sounds. Because sounds' influence on vision depends upon the strength of the visual signal, we hypothesized that heard footsteps should increase detection sensitivity only when the visual stimulus is weak. To test this hypothesis, we analyzed data from Thomas & Shiffrar (2010) to see whether the detectability of the visual signal determined the degree to which footstep sounds improved detection of point-light walkers. We obtained percent correct for each movie presented in silence (range 33-100%). We then split all movies into two groups based on difficulty. A 3x2 mixed measures ANOVA with sound condition as the between-subjects factor (silence, tones, footsteps) and difficulty as the within-subjects factor (easy vs. hard) revealed a main effect of sound, difficulty and a sound X difficulty interaction. Subsequent analyses revealed that footsteps improved visual sensitivity only for “hard” movies, supporting our hypothesis. A follow-up experiment replicated and extended these results.

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23.515 Search asymmetry in perceiving walkers: Inversion effect and biological motion stimuli

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We have reported that searching an approaching walker among 2-5 deviating walkers was more efficient than searching a deviating walker among approaching walkers for small deviation angles (6-12 deg), but the search asymmetry got opposite/reversed for large deviations (30-60 deg) (Ono & Kitazaki, VSS 2010). In the present study we aimed to investigate inversion effect of walkers' search asymmetry and to apply point-light display (biological motion) to the search asymmetry. In Experiment 1, we presented 3, 4, or 6 human walkers (front view, smooth shaded 3-dimensional computer graphics), one of which was approaching to or deviating from the observer, while the other walkers were deviating from or approaching to the observer, respectively (deviation angle: 6, 12, 30, or 60 deg). The ori-

entation of walkers was upright or inverted. Ten observers were asked to identify one approaching or deviating walker as accurately and quickly as possible. Identification of an approaching walker among deviating walkers was quicker than the opposite identification with small deviation (6 deg), but that of a deviating walker among approaching walkers was quicker with 30 and 60-deg deviations for both upright and inverted walkers. Visual search of inverted walkers was less efficient than upright walkers especially with small deviations. In Experiment 2, we conducted the same experiment using biological motion stimuli (18 point-lights on joints). We found that the reaction time was much longer than computer-graphics walkers with small deviations (twice for 6-deg and 1.5 times for 12-deg) and that the search asymmetry and its reversal were very similar to those of upright computer-graphics walkers. These results suggest that searching walkers with small deviations requires walker-specific social-cognitive processing in which approaching is more important than deviating, while the search with large deviations is related with ordinary object perception in which deviation properties are salient.

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23.516 Listening to footsteps modulates invisible biological motion processing

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Walking is arguably the most frequent movement in bipeds (e.g., humans) and quadrupeds, and is often accompanied with footsteps. Here we report an investigation into the effects of auditory cues on invisible biological motion processing. A standard high contrast dynamic noise pattern was presented to one eye, and a test motion sequence (i.e., a point-light walker) was gradually introduced to the other eye so that it was rendered invisible through interocular suppression at the beginning of each trial. We measured the time for the stimulus to break from noise suppression and begin to gain dominance. Meanwhile, auditory beeps either congruent or incongruent with the pace of the point-light walker were presented. Results showed that point-light walkers paired with congruent auditory beeps emerged from suppression into awareness faster than those paired with incongruent beeps. The modulation effect, however, was strongly impaired when the biological motion stimuli were shown upside down. Our findings suggest that auditory cues can be automatically integrated with biological motion processing even in the absence of conscious awareness.

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23.517 Beat them to the punch: Rapid recognition of boxers among walkers with a “punch detector”

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Searching for a person in a crowd is an important task. But arguably, an even more important task is finding (and evading) a fighting person in a crowd. Biological motion research, however, has been heavily tilted towards the use of walking figures. Here we utilized a visual search paradigm to examine what information is essential in detecting abnormal activities.

We employed two target-distractor combinations (a boxer target among walkers distractors, and vice versa), and three different set sizes (3, 6, or 9 items). Observers indicated the presence or absence of a target action. The first block included intact point-light actors; the second block was composed of scrambled actors in which each joint's initial position was spatially scrambled. All point-light actors rotated in depth.

We observed a search asymmetry between boxers and walkers: Searching for a boxer among walkers was faster and more efficient than searching for a walker among boxers. In fact, the boxer popped out, suggesting the search for boxing actions occurred preattentively. Configural information cannot explain the search asymmetry, because the same effect was obtained with scrambled point-light actors. ROC analyses showed that local motion signals (i.e., average and maximum velocity and acceleration) could not explain this effect, as they neither showed the search asymmetry, nor reached human performance level. However, reverse correlation techniques showed that the observers' responses did cluster around the “punch” event of a boxer, but not around any specific posture in the walker stimuli. These findings suggest that there is a low-level “punch detector”, that, we show, is also view-point independent. This detector is action cat-

egory specific, and is similar to, but different from the “life detector” postulated in previous research. It helps humans identify aggressive punching behavior in a crowd. We tentatively suggest that this mechanism operates through a subcortical “threat”-detection mechanism.

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23.518 Anticipating The Actions Of Others: Do Goalkeepers Use Local or Distributed Information?

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When humans observe the actions of others, they can often accurately anticipate the outcome of those actions on the basis of information available in the actor's movement. This ability was investigated within the context of blocking a penalty kick in soccer, where extreme time constraints force the keeper to anticipate kick direction on the basis of information in the kicker's movements before foot-to-ball contact. In this study, we focused on the contribution of movement information that is local to a particular body segment versus information that is distributed across multiple segments. Using a motion capture system, we recorded the joint locations of experienced soccer players taking penalty kicks. The motion data were used to create animations of a point-light kicker approaching and kicking a ball. The animations ended at foot-to-ball contact. Subjects viewed the animations from the keepers' perspective and made judgments of kick direction (left/right). Previously, Diaz et al. (2010) found that judgments were highly correlated with two sources of local information (hip rotation and location of ball contact), and two sources of distributed information identified using principal components analysis. This experiment provided a more direct test of the contributions of these four sources of information. Subjects were trained for 360 trials using animations with veridical movement information and trial-by-trial feedback. Following training, 180 normal stimuli were intermixed with 72 catch trials in which the usefulness of the information sources identified by Diaz (2010) was systematically manipulated, and feedback was withheld. Subjects performed at chance levels when only hip information was reliable, and were able to judge kick direction when ball-contact information was made unreliable but distributed was left intact. In sum, the results are consistent with the use of distributed information, or some yet to be identified source of local information.

Face perception: Wholes and parts

Saturday, May 7, 8:15 am - 12:15 pm

Vista Ballroom, Poster Boards 519 - 533

23.519 Identification of similar faces in the peripheral visual field

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Faces are complex stimuli which only need a few simple features configured in a specific way to allow detection as a face. However, we rely on more detailed information about the shapes and arrangements of these features when we identify faces. We want to understand how the brain differentiates between faces based on their similarity. In this study, we aimed to elucidate animals' abilities to discriminate human faces based on parametric differences between the faces. Animals were trained to perform a 2 alternative forced choice, match-to-sample task. In this task, two faces appeared in the peripheral visual field, equidistant on either side of the fixation point. After a variable delay, the sample face appeared centrally. The fixation point was extinguished after a 350-1250 ms delay and the animal had to make a saccade to the face in the periphery which matched the sample to receive their reward. Each day, we used 5 computer generated faces which varied holistically and parametrically from each other along 2 dimensions. This allowed us to obtain two independent measures of face similarity - one of which is based on the parametric variations which we used in generating the images, the other being the performance of the animals. We found that the animals' performance for a given pair of stimuli depended on the degree of similarity of the stimulus pair to each other. For the same face pairs, performance was strongly correlated between the animals ($R^2=0.74$). However, performance sometimes varied depending

on the identity of the central face. This variance was seen in both animals and was not consistent between the animals for identical stimuli ($R^2=0.45$). These data suggest that face similarity is conserved between animals, but they may approach it with different preferences and strategies.

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23.520 Face Recognition as a Function of Image Resolution and Viewing Distance

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The fundamental challenge in facial recognition lies in understanding the role that different facial features play in our judgments of identity. Notable in this regard are the relative contributions of the internal features (eyes, nose and mouth) as well as the external features (hair and jaw-line). Past studies that have investigated this issue have typically used high resolution images or high quality line drawings as facial stimuli. The results obtained have therefore been most relevant for understanding the how faces are identified at close range. Given that real-world viewing conditions are rarely optimal, it is important to know how image degradation (such as loss of resolution caused by large viewing distances) influences our ability to perceive those internal and external features. We report experiments designed to address this issue, and our data characterizes how the relative contributions of internal and external features change as a function of image resolution and viewing distance. While we have replicated results of previous studies that have shown internal features of familiar faces to be more useful for recognition than external features at high resolution, we found that the importance of the two feature sets is flipped as resolution decreases. Additionally, our results suggest that the visual system uses a highly non-linear cue-fusion strategy in combining internal and external features along the dimensions of image resolution and distance, and that the configural cues that relate the two feature sets play a profoundly important role in judgments of facial identity.

23.521 Recognizing Facial Slivers

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Imagine vertically compressing a facial image to half its original width. This grotesquely distorted face would be expected to be much less recognizable relative to the original given the marked changes in facial configuration the compression introduces. We have found, however, that even extreme compressions, leading to sliver-like faces that are just one-sixth the original width or height, leave identification performance almost entirely unaffected. This result has important implications for the nature of configural information that participates in recognition. Although there is currently no precise definition of ‘facial configuration’, it is implicitly assumed that its primary constituents are the mutual spatial relationships of the internal features (eyes, nose and mouth). Here, we report experiments designed to characterize how the relative contributions of internal and external features (hair and jaw-line) change as a function of image compression. We find that even at moderate compressions, the absolute sum of recognition performance with internal features alone on the one hand and external features alone on the other, is significantly lower than performance based on internal and external features together. This highly non-linear relationship suggests that the definition of ‘facial configuration’ must crucially include spatial relationships linking internal and external features rather than merely the mutual arrangement of internal features alone. More generally, recognizing whole faces appears to involve non-linear cue-fusion for integrating internal and external features, rather than being the sum of two independent processes, one for internal features and the other for external ones.

23.522 Why are face composites difficult to recognize?

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The composite task is widely used in face processing to test issues of holistic processing. In this task, composite faces are formed by taking the top half of one face and pairing it with the bottom half of another. A large body of data has demonstrated that judgments of one half are affected by the identity of the irrelevant half, particularly when the two halves are aligned into the configuration of a normal face, and this interference is thought

to be due to mandatory holistic processing of a face. However, very little work has been addressed at understanding the nature of the interference observed in the composite task. We examined this issue by creating composites from faces that were identical except for the spacing of the eyes. In the experiment, Chinese participants viewed Chinese and Caucasian composites (both halves of each face were always the same race), and had to judge whether the top halves of two successive composites were identical or different. The complete design of the composite task was used, so that the composite effect is demonstrated by the top/bottom congruency \times alignment interaction. Top (target) halves were always identical except (on half the trials) for the spacing of the eyes; bottom halves were either identical or from different faces. The results showed a significant three-way interaction between congruency, alignment, and orientation, which demonstrated a composite effect but only for aligned, upright faces. This effect was further modified by the significant four-way interaction between congruency, alignment, orientation, and race as our Chinese participants showed a stronger congruency effect for Chinese than Caucasian faces, but again only when they were aligned and upright. These results show that in the composite task, changes in irrelevant face information interfere with the processing of configural relationships within the target region.

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23.523 It is easier to remember two faces than a single one

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Theories of visual working memory (WM) assume that encoding produces independent "internal replicas" of the to-be-remembered items and describes retrieval as a template matching process. The present investigation questions this basic assumption.

Method. Observers were asked to perform an old/new tasks with a short time interval between the memory array and the probe item. The memory array always comprised low-discriminable items generated through a morphing procedure (human faces, cars, or cat faces). The memory load was varied.

Results. For car stimuli, recognition performance decreased with set size. Contrary to previous results, for face stimuli recognition performance was higher when observers were asked to remember two or three faces, rather than only one (Experiment 1). For caucasian participants, the size of this effect was larger for caucasian faces, smaller for afro-american faces, and smaller for cat faces (Experiment 2). The disadvantage of the memory load of one face with respect to two or three faces for recognition performance could not be explained by the lower discriminability of the face stimuli within the morph continua with respect to the car stimuli. In Experiment 3, we showed that the face stimuli were more easily discriminable among each other than the car stimuli.

Conclusions. The present results are inconsistent with WM models assuming that items are stored discretely in different slots and suggest that different perceptual coding schemes are used by the brain for low-discriminable faces and non-faces. The novel results concerning the face stimuli are compatible with synthetic vision algorithms based on principal components analysis, such as the Eigenfaces model. These results support the hypothesis that, for low discriminable faces, information is not represented independently in WM, but rather in relation to the other items appearing in the same spatial configuration (Jiang, Olson, & Chun, 2000).

23.524 Holistic processing for own-, other- and mixed-race faces is modulated by awareness of race category

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People are worse at recognising, and show less holistic integration, for other-race faces. Debate continues on how much this is based on perceptual experience versus other factors such as motivation to individuate members of another race. Here we tested integration, using the part-whole task, and racial classification for four faces types matched on basic skin tone: white faces with white features, black faces with black features, white faces with black features and black faces with white features. Task order was manipulated between participants, with both Caucasians and Non-Caucasians

tested. If experience is the key factor, integration should be stronger for more experienced faces, regardless of task order (WW>BB>WB=BW, both groups). If motivation or awareness of race is key, then task order should influence the results such that completing the categorisation task first leads to more integration for faces more like one's in-group (C: WW>WB>BW>BB; Non-C: WW=WB=BW=BB). Race categorisation in mixed-race faces was most affected by changes to the eyes for both Caucasian and non-Caucasian participants. Caucasian participants who completed the part-whole task first showed significant advantages for wholes over parts for all four faces types. However, Caucasian participants who completed the race categorisation task first showed a significant part-whole effect only for black faces with white features, with reduced accuracy on most whole conditions. Non-Caucasian participants showed an overall similar pattern of results, although those who did the part-whole task first only showed significant part-whole effects for black faces with black features and black faces with white features. Caucasian and non-Caucasian groups were closely matched on experience with black faces, but Caucasian participants had higher levels of experience with white faces. This experiment suggests that experience and awareness of race both affect the level of holistic processing for faces, but awareness of race has more influence on integration.

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23.525 Contextual grouping cues modulate holistic face perception

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Facial features are processed interactively and integrated into a holistic perceptual unit, unlike those within objects, which are processed in a more feature-based manner. This holistic nature of face perception is robust even when discouraged via explicit task instructions. However, it is unclear whether holistic perception mechanisms are truly impenetrable or whether instead perceptual cues that discourage the grouping together of facial features might disrupt such mechanisms. The degree to which faces were perceived holistically was assessed in the context of perceptual cues that either encouraged or discouraged the grouping of information within the faces. Holistic perception was measured using a composite task that required participants to make same/different judgments about a cued part (either the top or bottom) of sequentially presented chimeric faces. This task indexes holistic perception by measuring the degree to which performance is impacted by the task-irrelevant face halves. Here, the face halves appeared against the backdrop of different rectangles, which were either aligned or misaligned – although, critically, the face parts themselves remained aligned. In the misaligned condition, the color of the two background rectangles also differed from each other, a manipulation designed to further discourage the grouping together of the two parts. Results revealed that holistic face perception was significantly modulated by grouping context: when the color and alignment of the background rectangles discouraged perceptual grouping of the face parts, the faces were processed less holistically than when the rectangle features encouraged grouping. Consistent with the notion that this effect reflected disrupted holistic processing, the same grouping cues failed to similarly impact performance involving non-face objects (e.g., cars), which are typically not linked with holistic processing. This contextual influence on holistic face perception is striking, given previous evidence of the impenetrability of holistic face perception.

23.526 The Effect of Changing External Features on the Recognition of Headscarf-Wearing Faces

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The Muslim headscarf (hijab) conceals the hair and other external facial features, and so may have implications for the ease with which faces are remembered. To investigate this, 24 South Asian females were photographed wearing the headscarf (HS), with their own hair (OH) visible, and with all external features cropped (CR). Participants viewed a number of photographs during the learning phase and then subsequently viewed the same faces intermixed with distracter faces. Participants were required to decide whether each face had been seen in the learning phase. Crucially, faces were either in the same state in the two phases, or switched between two different states. Some participants also completed a social contact questionnaire which was used to measure the quality and quantity of contact

with South Asian people, White people and, with females wearing a Muslim headscarf. Surprisingly, when the hair state was the same at learning and test, performance was almost the same (approximately 83%) for OH, HS, and CR conditions. However, when the hair status of the pictures was switched between learning and test phases, performance dropped dramatically to approximately 64%. In addition to this, contact with South Asian people was positively correlated with performance for the OH stimuli. Furthermore, for the CR stimuli there was a positive correlation between contact with headscarf wearing females and performance on the recognition task. These results imply that there is sufficient information in the internal features of faces for optimal performance in these experimental conditions and that social contact may mediate the size of any bias. The drop in performance when hair status changes suggests that the hijab or hair may sometimes act as a perceptual mask to the face stimulus, in much the same way that a wig can act as a disguise in certain circumstances.

23.527 The role of featural and configural information for perceived similarity between faces

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An important aspect of face recognition involves the role of featural and configural information for face perception (e.g. Tanaka and Farah, 1993; Yovel and Duchaine, 2006; Rotshtein et al, 2007).

In our study, we investigated the influence of featural and configural information on perceived similarity between faces. Eight pairs of male faces were chosen from our digital face database (<http://faces.kyb.tuebingen.mpg.de>). The texture and the face shape for both faces in a pair were equalized to create 2 basis faces that differed only in their inner facial features and their configuration, but not in face shape or texture. A computer algorithm allowed to parametrically morph the features, the configuration, or both between the two basis faces of a pair. In our case the morphing was done in 25% steps.

24 participants rated the similarity between pairs of the created faces using a 7-point Likert scale. The faces to compare came from the same basis face pair and could differ either in features or in configuration by 0%, 25%, 50%, 75% or 100%.

The results revealed that for the same amount of morphing, faces differing by their features are perceived as less similar than faces differing by their configurations. These findings replicate previous results obtained with less natural or less controlled conditions. Furthermore, we found that linear increases of the difference between both faces in configural or featural information resulted in a nonlinear increase of perceived dissimilarity. An important aspect for the relevance of our results is how natural the face stimuli look like. We asked 24 participants to rate the naturalness of all stimuli including the original faces and the created faces. Despite numerous manipulations, the vast majority of our created face stimuli were rated as natural as the original faces.

23.528 Priming global and local processing of composite faces: Revisiting the processing-bias effect on face perception

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We used the composite-face illusion and Navon-stimuli to determine the consequences of priming local or global processing on face recognition. The composite-face illusion is observed in face-matching tasks and reflects the difficulty to ignore one half (e.g., bottom) of a face when the two aligned halves are incongruent. In each trial participants first responded to the global or local level of two Navon-stimuli and then matched the upper halves of two face-composites presented sequentially. Global processing of Navon-stimuli increased the illusion compared to local processing, as evidenced by larger reduction in sensitivity in the incongruent relative to congruent face-composites. Importantly, although incongruence induced a bias towards "Different" responses overall, this bias was not modulated by

priming. We conclude that the level of processing the prime influenced the processing of composite-faces such that global processing of Navon-stimuli augmented holistic processing of the faces relative to local processing.

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23.529 A dynamic photorealistic average avatar - separating form and motion

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Moving faces, unlike static face images, contain information about change in emotional expression, paralinguistic cues and facial speech. Facial motion also provides cues for identification and categorisation. Acquiring facial motion is complex and generally requires marker-based motion capture, which may only sparsely sample facial motion, or expensive 3D scanning equipment. Presenting realistic facial motion without structural cues to identity, as required to study identification from facial motion alone, is challenging, as accurate animation of an average face is difficult to achieve. When making a static, expressive average face, subjects are asked to hold a constant expression. However, when attempting to average across video sequences of different people, we are faced with an expression correspondence problem. How do we ensure that we are averaging the same expression instantiated on different faces? We present a novel, dynamic facial avatar that overcomes the expression correspondence problem. The avatar is generated from normal video sequences of subjects talking to camera. A separate expression space is created for each individual by registration across frames of their sequence using a biologically-plausible optical flow algorithm and Principal Component Analysis (PCA). Example expressions from a selected individual are then projected into the expression spaces of all models and the average of the resulting images calculated to remove static facial form information. These average images are subsequently subjected to the same registration and PCA process to provide a new expression space for the average avatar. This avatar allows the projection of any individual's facial motion, sampled at pixel resolution, onto a photorealistic identity-free face enabling motion information to be isolated from structural identity information. This strategy provides a much more precise representation of isolated facial movement than can be achieved using standard techniques.

Acknowledgement: EPSRC

23.530 Relative Independence of Face and Body Posture Processing

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Recent research has examined how different aspects of the face and body affect configural processing. Other research has demonstrated that the absence of a head can influence body perception. An open question remains as to the extent to which faces and bodies influence the visual perception of the other. In this study we determined whether face discrimination and the face inversion effect were affected by constant or varying body postures and whether posture discrimination and the body inversion effect were affected by constant or varying faces. Three experiments used a sequential same-different task in which participants compared either faces or bodies in upright or inverted orientations. Stimuli in all conditions were bodies in different postures with distinguishable faces. Across experiments and conditions, face and body variability was manipulated. The perception of body postures with a constant stock face was compared with body postures with systematically varying faces. Likewise, the perception of faces with a constant stock body posture was compared with systematically varying body postures. Results indicated that body posture discrimination was affected by variation in faces to a greater extent than face discrimination was affected by variation in body postures. Discrimination of both faces and body postures was greater for constant compared to varying conditions. However, variability did not appear to influence the magnitude of the inversion effects. The extent to which face and body processing are independent of one and other are considered in the context of current theories of configural processing.

23.531 Local Processing in the Navon Task Slows Face Gender Discrimination

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Configural processing is important for the processing of faces. However, it is unclear if configural face processing is not rooted in a more generic mechanism. Evidence in favor of a generic configural mechanism comes from reports that face recognition deficits in high functioning autism are correlated with local processing performance of the Navon letters task, suggesting an overall configural deficit. In addition, a number of previous studies have shown poorer face recognition memory in healthy participants following the processing of the local features of a Navon task. It has been suggested that these effects on face recognition reflect transfer-inappropriate processing induced by the local processing in the Navon task. However, these effects have typically been shown when the Navon task is performed between the encoding and retrieval stages of a memory task for unfamiliar faces. In the present study, we examined if such effects also extend to gender discrimination of faces, which is a highly overlearned face discrimination task. Fifteen participants performed a global or local Navon task for two minutes, and then intermittently made face discriminations among more trials of the same Navon task. The order of local and global Navon task blocks was counterbalanced across participants. Results indicated that gender discrimination was significantly slower following performance of the local Navon task compared to following the global Navon task. These findings indicate that local processing of non-face stimuli, as induced by performance of the Navon task, can also spill over to the processing of faces. This suggests that the configural processing that is used for face processing is also used for other types of stimuli, and may be part of a more generic configural processing system.

23.532 Eye Movement in Face Change Detection Task

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Unlike reading or scene perception, the utility of eye tracking for purposes of studying face processes is limited given that recognition typically occurs within one or two saccades. However, if processing time is extended for a longer duration, eye tracking can be useful for uncovering the strategies mediating face discrimination decisions. To achieve this, we employed a change detection paradigm where two faces were continuously presented with an intervening noise mask until the participant made a "same" or "different" response. The faces were either identical or differed in their featural or configural properties and shown in their upright and inverted orientations. Featural differences were either in the size of the eyes or the mouth. Configural differences were either in the horizontal distance between the eyes or vertical distance between nose and mouth. Eye movements were analyzed in terms of the location of the first fixation, location of last fixation and location of aggregate fixations. Initial fixations to upright face were predominantly directed to the eye area whereas first fixations to inverted face were equally distributed to eyes and the nose area. In terms of accuracy, inversion differentially impaired the detection of featural and configural changes in mouth region than the eye region even though more and longer eye fixations were allocated to this area. Overall, the nose was attended to more on configural change trials than on featural change trails regardless of the orientation. The analysis of last fixations revealed that changes were more likely to be detected if the last fixation was located in the region where the change occurred indicating that the eye movement behavior was predictive of change detection performance. In short, this study showed that face strategies are accurately reflected in eye movement behaviors when the task is self-paced and requires additional processing time.

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23.533 The effect of perceptual expertise on visual short-term memory

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 Visual short-term memory (VSTM) capacity is larger for faces than other complex objects. Inversion reduces capacity for faces more than nonfaces (Curby and Gauthier, 2007). These findings suggest that VSTM is not influenced simply by object complexity, but also by the encoding processes employed by face experts.

Previous research (Scolari, Vogel and Awh, 2008) found that perceptual expertise enhances the resolution but not the number of representations in working memory. In other words, people have a more detailed memory, instead of a larger WM capacity, for faces than nonfaces. Since we are more expert at recognizing own-race than other-race faces, we investigated whether the own-race advantage is due to a higher resolution of own-race face representations.

Six study items (Chinese and Caucasian faces as well as shaded cubes) were simultaneously shown on screen on each trial. After a short delay, a single image was presented. Participants were asked to judge whether this image was the same or different from the item that originally appeared in that location. Performance of both cross-category changes (i.e. face to cube, cube to face) and within-category changes (i.e. face to face, cube to cube, color to color) was measured.

Neither own-race nor other-race faces showed an inversion effect when stimuli changed between categories. However, an inversion effect was found for both own-race and other-race faces when stimuli changed within a category. These results suggest that both own-race and other-race faces are stored with high resolution in working memory.

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Face perception: Disorders

Saturday, May 7, 8:15 am - 12:15 pm
 Vista Ballroom, Poster Boards 534 - 545

23.534 Holistic face perception impairment in acquired prosopagnosia as evidenced by eye-gaze-contingency: generalization to several cases

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Gaze-contingency is a method introduced by Rayner (Cog. Psy., 1975) to investigate the perceptual span in reading by selectively revealing/masking a portion of the visual field in real time. Recently, we introduced this approach in the field of face perception, showing that a brain-damaged patient with impairment limited to face recognition (acquired prosopagnosia, patient PS) presents with the reverse pattern as normal observers: almost no further decrease of performance when only one feature at a time is available (foveal window condition), but a very large impairment when the fixated feature is masked (mask condition), forcing holistic perception (Van Belle et al., JOV 2009: <http://www.journalofvision.org/content/9/8/541>; Neuropsychologia, 2010). Here we extend these latter observations to two cases of acquired prosopagnosia with unilateral right hemisphere damage: GG (Busigny et al., Neuropsychologia, 2010; lingual, fusiform and parahippocampal damage) and LR (Bukach et al., J. Cogn. Neurosci., 2006; anterior pole damage). Both patients also present with impairment in visual recognition limited to faces. They were tested in a delayed face matching task with a full view, gaze contingent window, and gaze contingent mask condition. Similar to PS and contrary to normal observers, both patients were significantly more impaired with a mask than with a window, demonstrating problems with holistic face perception. These observations support a generalized account of acquired prosopagnosia as a selective impairment of holistic face perception, and imply that holistic perception is a key element of normal human face recognition. Furthermore, the similar behavioral pattern of all three patients despite their very different lesion locations supports a distributed network view of the neural face processing structures, meaning that the key function of face perception requires the activity of several brain areas of the right hemisphere and their mutual connectivity.

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23.535 Holistic processing of unfamiliar faces during social judgments in acquired prosopagnosia

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Prosopagnosia, an impairment at individualizing faces classically caused by brain damage, has been linked to a deficit in holistic face processing. Holistic perception of facial information, however, does not only play a pivotal role during face identity judgments but also for judgements of facial expression (Calder et al., 2001). In a similar vein, there is recent evidence that social judgments concerning stable characteristics of other people such as their trustworthiness seem to rely strongly on the holistic processing of relatively invariant person-specific facial cues (Todorov, Loehr, & Oosterhof, 2010). In consequence, if prosopagnosics are unable to process person-specific facial cues holistically, and if social judgments require such kind of processing, prosopagnosic patients should also demonstrate a marked deficit in face-based trait judgements. To address this issue empirically, we asked a well-characterized case of acquired prosopagnosia (PS) with a marked deficit in holistic face processing when identity judgments are concerned (Ramon, Busigny, & Rossion, 2010) to rate a set of standardized same-race faces on trustworthiness. The data revealed that PS provided trustworthiness judgments within the normal range. To further inquire whether her judgments reflected holistic processing of facial features, PS was also asked to evaluate trustworthiness in the context of a composite face paradigm (see Todorov et al., 2010). Similar to healthy controls, PS judged facial halves more trustworthy when aligned with trustworthy than with untrustworthy halves, despite the instructions to ignore the aligned parts. These findings thus challenge the assumption that prosopagnosia is characterized by a general impairment of holistic processing during face perception. As such, the results rather support the view that abnormal holistic processing of an individual face in prosopagnosia depends on the type of judgment required and potentially on the fine-grained degree to which – rather than if – a judgment relies on the integration of person-specific facial information.

23.536 Developmental Prosopagnosia: A childhood case study

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Developmental prosopagnosia refers to an inability to recognize faces despite typical intellectual functioning, emotion and object recognition, and no evidence of brain injury. Very little is known about this disorder in children. We present a case study of a child, henceforth referred to as B, who reported extreme difficulty in recognizing faces. Participant: B is a healthy 7 year old male with no history of neurological or behavioral disorder. His parents report that he is above-average in intelligence and very social. He has no history of visual impairment other than a deficit in face recognition. Methods: We evaluated B's face recognition skills using a variety of measures for which we have been collecting normative data. We examined his ability to recognize faces, discriminate between faces, identify emotion, and recognize objects. A clinical neuropsychologist also evaluated B using a wide variety of measures. Finally, we employed a training program to improve B's ability to recognize the faces of familiar people in his life. Results: On our test of face recognition, B answered correctly on 46.8% of trials (50% is chance); average performance of 8 year olds on this test is 80% (sd=10.7, n=43). These results provide evidence of a severe deficit in face recognition. B showed no evidence of a similar deficit in the ability to discriminate faces, recognize objects, and identify emotion. The neuropsychological evaluation also found a deficit in face recognition despite intact object recognition, memory, emotion recognition, and above-average IQ. Finally, we successfully trained him to identify photographs of 30 familiar people; however, he used local characteristics of the photograph to recognize the faces. Discussion: This is one of very few studies of children with developmental prosopagnosia and the first comparison of a DP child using measures collected from a large sample of typical children.

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23.537 Abnormal adaptive coding of identity in congenital prosopagnosia

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Adaptive face coding mechanisms are believed to generate face norms, which represent the average characteristics of faces that have been experienced. Individual faces are coded relative to these norms, which are continually updated by experience. We investigated whether individuals with congenital prosopagnosia (CP), who report difficulty recognising faces and perform poorly on face recognition tests, have abnormal adaptive face coding mechanisms. We administered two face adaptation measures to 14 CPs to pinpoint their face processing impairments. The figural aftereffect reflects the dynamic updating of face norms, e.g., viewing 'contracted' faces shifts the norm in that direction, so that subsequently viewed undistorted faces are perceived as somewhat 'expanded'. The figural aftereffect reflects adaptation to general distortions of shape and may not directly tap coding of facial identity. The performance of CPs was indistinguishable from that of controls on this task, consistent with evidence that CPs process some shape-based information from faces e.g., gender. In contrast, the face identity aftereffect directly taps the mechanisms involved in the discrimination of different face identities. Adapting to an individual face temporarily shifts the norm closer to that face, facilitating identification of a computationally opposite identity. CPs demonstrated a significant identity aftereffect, consistent with the figural aftereffect results. However, unlike controls, CPs' impression of the identity of the neutral average face was not significantly shifted by adaptation, suggesting that the adaptive coding of identity is abnormal in CP. Further, the strength of the identity aftereffect for the average face correlated significantly and positively with performance on face recognition tests. CPs therefore show reduced aftereffects but only when the task directly taps the use of face norms used to code individual identity. These results are consistent with the finding that individuals with ASD, a developmental disorder associated with face identification difficulties, also show reduced face identity aftereffects.

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23.538 The right anterior temporal lobe variant of prosopagnosia

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Background: Prosopagnosia following right anterior temporal lesions alone has rarely been described, though functional imaging has suggested that face processing involves regions like aIT, anterior to the core face processing network (the fusiform face area, FFA, occipital face area, OFA, and superior temporal sulcus, STS). Prior work has hypothesized that anterior temporal lesions could cause an associative or amnesic variant of prosopagnosia, though it has been questioned whether this can be independent of a multimodal semantic deficit for people. Objective: Our goal was to determine the type of face recognition deficit after lesions limited to the right anterior temporal lobe. Method: We evaluated face recognition, perception and imagery as well as semantic knowledge about people in two subjects with prosopagnosia following herpes encephalitis causing right temporal pole lesions, in whom fMRI confirmed the integrity of FFA, OFA, and STS. Results: Both subjects performed normally on nearly all tests of perception of facial configuration and features, discrimination of face gender, and face detection. Subject R-AT2 was mildly impaired in discriminating changes in identity when expression also varied, and vice versa, suggesting some difficulty with invariant representations. Subject R-AT3 had mild impairments in discriminating eye shape and mouth changes, but far less severe than in subjects with FFA/OFA damage. In contrast, both subjects had markedly impaired face imagery. Finally, both subjects performed well on identifying famous names and linking semantic data such as occupation to names, in contrast to another subject with bilateral anterior temporal lesions. Conclusion: The right anterior temporal variant of prosopagnosia is characterized

by impaired access to facial memories with relatively preserved face perception and semantic knowledge about people, consistent with an amnesic or associative functional subtype of prosopagnosia.

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23.539 Acquired prosopagnosia with spared within-class object recognition but impaired recognition of degraded basic-level objects

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Herschel is a 54-year-old man with bilateral occipito-temporal lesions following two strokes. A functional MRI scan showed bilateral fusiform face areas, bilateral face-selective activation in the posterior superior temporal sulcus, bilateral lateral occipital areas, but no right or left occipital face area. Herschel was severely impaired on tests requiring recognition of famous faces, unfamiliar faces, facial expressions, and facial gender. In contrast, he scored normally on within-class object and scene memory tests involving cars, houses, landscapes, tools, sunglasses, and handguns. His performance on a challenging car memory test requiring recognition in novel views and lighting was also normal. Herschel scored normally on a sequential matching task involving objects despite near chance performance on a parallel face matching task. His results provide strong evidence for the dissociability of face recognition and within-class object recognition. Herschel however reports object recognition problems in daily life, particularly in complicated scenes, and four tests requiring recognition of degraded basic level objects revealed impairments. In two of these tasks, stimuli from the Gestalt Completion Test and the Snowy Pictures Test were presented briefly (Ekstrom et al., 1976). We also tested Herschel with an Unusual Views Test and on a task requiring recognition of spatial frequency filtered photographs (Viggiano et al., 2004). In summary, Herschel's performance indicates that face recognition and within-class object recognition involve different mechanisms, but his surprising dissociation between within-class and basic level object tasks raises interesting questions and merits further testing.

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23.540 Ensemble Encoding in Congenital Prosopagnosia

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Individuals with congenital/developmental prosopagnosia have difficulty recognizing faces. They also have been reported to have difficulty with more global processing of other types of complex stimuli. Here, we tested for both of these effects using a single common stimulus display, so that the two deficits could be directly compared in the same experiment. We presented groups of faces, because typical observers precisely perceive the mean of the ensemble expression or identity in such groups. We created an identity stimulus set, or "wheel", by morphing incrementally between three distinct identities from the Ekman face gallery. Additionally, using only one identity from the gallery, we created an emotion stimulus wheel by morphing between the happy, angry, and sad versions of that face. During the experiment, congenital prosopagnosics and matched controls viewed sets of 18 faces varying in either identity or emotion (in separate blocks), and were asked to estimate the average identity or emotion of each set. Participants responded by choosing the identity or emotion from the stimulus wheel that corresponded to their perception of the average. Importantly, the face sets were presented in both upright and inverted viewing orientations (in separate blocks). For upright face sets, prosopagnosics were impaired in their ability to estimate the average for both the emotion and identity tasks. In contrast, prosopagnosics performed equivalently or better than controls in the inverted conditions in both tasks. These findings suggest that prosopagnosics are capable of extracting ensemble information about low-level features in faces, but are impaired at high-level (upright face specific) ensemble perception.

23.541 Psychophysical and Neural Investigations of Congenital Prosopagnosia

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Congenital prosopagnosia (CP) is a specific deficit in identifying faces thought to be heritable and not the result of stroke or other brain injury. Functional brain imaging (fMRI) in CP has not reliably found differences between CPs and controls in ventral visual cortex, but rather reduced grey matter or connectivity between visual cortex and temporal/frontal lobe (Avidan & Behrmann, 2009). Here we reexamine the hypothesis that CP is associated with differences in face selective regions in visual cortex. We scanned 8 CPs who show poorer performance than controls on various tests of face recognition including recognition of famous faces, the Cambridge Face and Memory Test, but not in recognition of famous places, or recognition memory for scenes and objects. During fMRI, subjects fixated and performed a one-back task while viewing blocks of faces, places, and objects. Previously published data (Golarai et al 2010) from 9 adults who participated in identical experiments served as control. In each subject, we drew anatomical ROIs in ventral temporal cortex (VTC), excluding early retinotopic areas and the anterior 1/3 of temporal cortex. In CP subjects, in the right VTC only, we found significantly fewer face-selective voxels (faces>objects) than in controls. There were no differences between groups in the spatial extent of object- or place-selective activations. To examine differences in signal change, we extracted signals from independent data. Face selective voxels in the right VTC of CPs showed a selective decrease in the response amplitude to faces relative to controls. However, groups did not differ in anatomical ROI size or the average model fit to the data in the ROI. These data suggest that congenital prosopagnosia may be associated with changes in both the extent and pattern of face selectivity in right ventral visual cortex.

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23.542 An Online Investigation of Face Training in a Large Sample of Developmental Prosopagnosics, Phase 1

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Case studies over the last 5 years have shown it is possible to improve face processing in developmental prosopagnosics (DPs) through cognitive training. Though these studies are promising, it's unclear whether face processing can be improved in a larger sample of DPs. Moreover, these studies did not sufficiently characterize the real-world significance of training-related improvements. We attempted to address these issues by recruiting a larger sample of DPs to perform an intensive face training program (45 min/day for 15 days) aimed at improving configural/holistic processing of faces. This program has shown previous evidence of training-related improvements in individual cases (for example, see DeGutis 2007). To increase our sample we had subjects perform testing and training on the web while being in close communication with the experimenter. The assessment battery consisted of tests of face perception, memory, part and whole processing, and object processing. We compared the pre and post results of the training group with a group of DPs that were assessed before and after a 15 day wait period. The training group also completed a diary for 5 days before and after training to quantify potential real-world improvements. We found that, as a group, DPs significantly improved on accuracy and reaction time in the training task. Compared to the test-retest control group, trained DPs demonstrated significant improvements on whole trials in the part-whole task (similar to a recent intervention study with autistic children by Tanaka and colleagues (2010)). Unfortunately, group-level improvements were limited to the part-whole task and these improvements did not necessarily correspond with robust real-world improvements. In summary, it is possible to improve aspects of face processing in a larger sample of DPs through face training, but these improvements may be limited to the face processes trained and may be limited in their real-world implications.

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23.543 Holistic processing of face gender in developmental prosopagnosia

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Normal face identity recognition and gender recognition has been shown to rely on holistic and configural processing, as evidenced by recognition difficulties with face inversion, viewing scrambled face parts, and when recombining the top of one face with the bottom of another (composite effect). Face gender recognition, however, can also be successfully performed using parts-based analysis, such as using eyebrow thickness or pigmentation cues. In developmental prosopagnosia (DP), face recognition is severely compromised and evidence suggests that impaired holistic face identity processing plays a predominant role. However, DPs typically demonstrate normal face gender recognition. It may be that DPs' holistic processing deficits are more specific to face identity and that DPs engage holistic processing mechanisms to successfully recognize gender. Alternatively, DPs may have general holistic processing deficits with faces and recognize gender using more parts-based analyses. To test these alternatives, we assessed 9 DPs on face gender recognition ability, and tested their holistic processing of gender: comparing upright gender recognition to inversion and viewing scrambled face parts, as well examining the gender composite effect. Our results show gender recognition in DPs is not significantly different than normal controls. Both groups were significantly impaired at gender recognition by inversion and displaying scrambled parts, and these decrements in performance are similar in magnitude. Like controls, DPs also showed a significant composite effect for gender. This was reduced compared to the effect in healthy controls. Together, these results suggest that face gender is processed holistically in DPs and calls into question the assertion that DP is a generalized holistic processing deficiency.

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23.544 Eying the eyes in social scenes: Diminished importance of social attention in simultanagnosia

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Simultanagnosia is a disorder of visual attention that results from bilateral lesions to the parieto-occipital junction. These patients have difficulty seeing more than one object at a time. We previously reported that simultanagnosics allocate abnormally few fixations to the eyes of people in social scenes. Given that healthy individuals look at the eyes of others to infer people's attentional states, this finding might reflect that a) for simultanagnosics the attentional states of others are not a high priority or, b) these patients are unable to use the eyes to infer the attention of others. To distinguish between these two alternatives we monitored the eye movements of simultanagnosic patient GB, and healthy controls, while they 1) described social scenes, or, 2) inferred the attention of people in the scenes. Consistent with past work, healthy individuals tended to look at the eyes of others in both conditions, but significantly more so when explicitly inferring the attentional states of the people depicted. GB fixated the eye regions far less than controls while describing social scenes, but performed similar to controls when explicitly asked to infer attentional states. Thus, like healthy subjects, GB shares a top-down understanding that the eyes are an important source of information for the attentional states of others. However, when deriving scene information, this attentional information is not normally prioritized by simultanagnosic patients to the same degree as it is by healthy individuals. This indicates that when multiple objects in a scene are not available concurrently a key social attention cue -- eye gaze -- is not used, despite the fact that knowledge of the value of this cue exists.

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23.545 Posterior Cortical Atrophy: The role of Simultanagnosia in deficits of Face Perception

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When viewing a face, healthy individuals tend to fixate on upper regions, particularly the eyes, which provide important configural information. In contrast, individuals with face blindness (prosopagnosia) rely more on local features -- particularly the mouth. We have recently presented research on the neurodegenerative disorder posterior cortical atrophy (PCA), which is characterized by impairments in higher level visual processing -- including face perception. Common among PCA patients is simultanagnosia, an inability to perceive more than one object or detail simultaneously. One might consider simultanagnosia the most extreme form of a feature-based approach. Do PCA patients produce gaze patterns similar to those associated with prosopagnosia? Or, do their patterns reflect even more of a simultanagnosia-based local dependence. Three PCA patients, RB, SS, and AP, and their healthy controls, completed a same/different discrimination task in which images of faces were presented as cue-target pairs. RB exhibits a "ventral" form of PCA, while SS and AP are more "mixed" or "dorsal" in presentation. Nevertheless, all three patients show signs of impaired face perception and simultanagnosia when tested, even though only RB has reported face perception problems in everyday life. In contrast to previous research with prosopagnosic patients, the PCA patients each produced unique scan paths that focused on one aspect of the face: the forehead for RB, the nose for SS, and the left cheek for AP. Surprisingly, the regions selected by the PCA patients often contained minimal contrast and little configural or feature-based information, suggesting that they were having difficulty processing the face even at a featural level. These results suggest a role of simultanagnosia in the gaze fixation patterns of PCA patients that is not reflective of 'typical' prosopagnosia, and instead point to simultanagnosia as an underlying cause of the face perception deficits seen in PCA.

Perception and action: Pointing and hitting

Saturday, May 7, 8:15 am - 12:15 pm
Vista Ballroom, Poster Boards 546 - 554

23.546 Compressing Perceived Distance Through Real and Imagined Tool Use

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Accumulating evidence suggests that visual perception is scaled according to the actions of an observer. For example, reaching for an object with a tool results in a compressed perception of space. We examined the manner and extent to which these illusions arise. In Experiment 1, participants estimated their distance from targets positioned 6-100 ft. away. Participants who illuminated the target with a laser pointer consistently judged it to be closer than those who pointed at the target with a baton. The magnitude of the underestimation increased with physical distance, indicating a non-uniform compression of space. Experiment 2 examined whether object interaction always results in spatial compression. Participants estimated the distance of targets 6-44 ft. away while holding the nozzle of a shop-vac that was running in either 'vacuum' or 'blower' mode. Interactions involving both attraction and repulsion resulted in targets being perceived closer compared to a non-interactive control condition. This suggests that object interactions, regardless of their form, result in compressions in perceived distance. Moreover, Experiment 3 showed equivalent spatial distortions among participants who imagined interacting with targets, indicating that implied or imagined interactions can have the same perceptual consequences as physical interactions. Finally, Experiment 4 explored whether the perceptual distortions that result from tool use persist in memory after the interaction has terminated. Participants initially described small scenes positioned 17 - 74 ft. away, and were given a surprise memory test in which they indicated the distances of each scene on a scale model of the environment. Participants who shined a laser pointer on the scenes while generating stories positioned scenes closer together in their models than did participants in a control condition, suggesting that perceptual distortions persist in memory beyond the moment of interaction.

23.547 Pointing accurately at a target doesn't require perceiving its location accurately

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Background. Action measures are commonly used to assess the accuracy of perception. However, actions can be calibrated to any stable perceptual experience because stability affords perceptuo-motor adaptation and prediction. Accuracy at action tasks therefore does not require accurate perception. To illustrate this, we measured dynamic pointing after locomotor adaptation. **Method.** We adapted participants to altered visual feedback during walking in an immersive panoramic virtual environment. Specifically, we doubled the visual gain of walking for one set of participants and adapted the second set to a normal gain. Following adaptation participants were tested in a dynamic pointing task while walking without visual feedback. That is, they started each trial pointing to an obliquely positioned target in the visual world and then tried to track the stationary (remembered) target with their hand while walking with eyes closed. **Results.** Participants adapted to a normal gain tracked the egocentric location of the targets relatively accurately. However, those adapted to doubled visual gain rotated their hand too rapidly even though they had never practiced pointing in the adapting environment. In contrast, explicit estimates of egocentric distance to similar targets did not differ as a function of adaptation condition, but underestimated egocentric distance in near space by a factor of about 0.75. Evidently adaptation altered spatial updating during locomotion without altering perceived target distance. **Conclusions.** A great deal of evidence suggests that egocentric distance is misperceived. Locomotor action measures, such as pointing, can be accomplished successfully if spatial updating of egocentric position is calibrated by experience. Thus any misperception of egocentric distance could be masked by such measures. Dynamic pointing tasks are informative about spatial updating, but they are not directly informative about the absolute scaling of perceived space. Actions can be calibrated to successfully reflect perceptuo-motor expectancies even in the presence of inaccurately scaled perceptions.

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23.548 Vision at high limb velocities: The importance of visual feedback for online control at high limb velocities early in a movement.

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Our previous work has shown that the use of vision during rapid upper limb reaches is optimal at high limb velocities. When providing vision only above .8 m/s, reaching endpoints are as precise as in normal vision and vision only provided below .8 m/s does not yield better endpoint control than without vision. In the current study, vision could be provided during 3 limb velocity windows above .8 m/s (Early [between .8 m/s & 1.4 m/s], Middle [between 1.4 m/s & 1.4 m/s] & Late [between 1.4 m/s & 0.8 m/s]). All possible combinations were used in a factorial design, yielding 7 vision conditions presented in a randomized order. Each vision condition was presented 20 times and a no vision condition was presented 140 times. Full vision pre- and post-tests were also performed. Our main dependent variables were tied to the variability (i.e., precision) and bias (i.e., accuracy) of movement endpoint distributions. In the primary movement axis, movement endpoint control was more precise when vision was provided in both the early and middle vision conditions than in the no vision condition. Providing vision in the late vision condition resulted in worse endpoint precision than the full vision pre- and post-tests. Our results indicate that visual information may be used most efficiently for endpoint precision when the limb is moving quickly early in a movement and in the portion of the trajectory that includes peak limb velocity. In contrast, vision above .8 m/s but below 1.4 m/s late in a movement does not appear to contribute to endpoint precision control. Thus, the use of visual information may be tied to the kinematics of a movement and be most effective early in a movement.

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23.549 Eye-hand coordination in rapid, goal directed movements

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Background: During rapid, goal directed reaches, a saccade typically lands close to the goal of the reach. However, it is not clear how eye-hand coordination impacts endpoint precision and accuracy of both movements.

Aim: We investigated whether eye-hand coordination and overall reach performance is significantly impacted by target duration and eccentricity. **Method:** Participants pointed rapidly to a high contrast target (white dot) that appeared at 1 of 8 different locations with equal probability. Each target was presented at a fixed eccentricity (range: 2- 12°) using a block design. In separate conditions, the stimulus was displayed for 100ms, or until the participant hit the screen with her finger. On each trial, the participant held a key down and maintained central fixation until the target appeared, then released the key and hit the target as quickly and accurately as possible. We recorded participants' eye movements, response latency, movement time and endpoint location. **Results:** For trials in which the target was displayed for 100ms, saccade latencies were distributed bimodally. For closer targets (2°), observers tended to initiate a hand movement before deploying a saccade. For further targets, saccades were deployed before hand movements. When the target was displayed until the touch, however, saccade latencies were consistently shorter than reach latencies across all target eccentricities. In both stimulus duration conditions, saccade accuracy was more strongly correlated with hand accuracy at 10-12° than for closer targets. **Conclusion:** Spatial and temporal correlations of eye and hand movements vary as a function of target eccentricity. We suggest this may be due to significant differences in the ability to localise targets at eccentricities greater than 10°. Results suggest eye and hand movements are coordinated with respect to a common map of visual space and are coordinated to improve accuracy and precision of both eye and hand movements.

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23.550 Distance-to-contact and not time-to-contact determines when a hitting movement is initiated

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When hitting moving targets, the hand or the hitting object has to be in the correct place at the correct time. That means that action must be initiated taking into account the velocity at which the object moves and has to be continuously updated. There are then two possibilities to calculate when to start the action: a) relying on the remaining distance for the object to arrive to the position where one wants to hit it (distance-to-contact) or b) relying on the remaining time for the object to arrive to the hitting position (time-to-contact). In our experiment, in different sessions subjects had to hit moving targets under harmonic motion with either reliable displacement amplitude or reliable maximum velocity. Results indicate that initiation of the movement is based on distance-to-contact instead of time-to-contact information. In both conditions the action is initiated when the target is at a relative distance (which is slightly different between conditions) from the hitting place, independently of the target maximum velocity. However, the temporal uncertainty present at initiation time is reduced with movement time for both conditions.

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23.551 Preventing falls in older adults: understanding postural instability under increasing visual-motor demands

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Visual information plays an important role in maintaining posture. The role of vision changes over the lifespan with children relying more on haptic information as they mature (Wann et al., 1998). The role of vision in the maintenance of posture is not well understood in older populations but it is possible that neuromuscular degeneration increases the reliance upon vision. Our poor understanding is particularly worrying because falls have been reported as the primary cause of premature death in older persons (Sattin, 1992). Standing balance is a reasonable predictor of increased risk of falling (Jarnlo, 2003, Winter et al., 1990). Nonetheless, many falls occur when someone is engaged in a visuomotor task (e.g. putting a key in a lock) rather than simply standing upright. A high-profile study has also suggested that contemplating the past or the future can influence postural stability (Macrae et al. 2010). We explored these factors whilst measuring postural stability in young (16-26 years) and older (70-87 years) adults using a novel kinematic measuring device. First, we measured standing

posture whilst participants tracked a moving target with a handheld stylus presented on a touch-screen laptop. The target moved at three speeds with stylus position recorded at 120Hz to provide accurate performance metrics. Second, we measured posture when participants reflected on future or past events. The results for tracking showed that error increased with higher target speeds and this led to greater postural sway. The speed manipulation interacted with age so the high speed target had a particularly large impact on postural stability within the older population. In contrast, the manipulation of past versus future contemplation had no effect on posture. These findings suggest that a full evaluation of postural stability should measure the impact of visuomotor tasks when establishing the risk of falls in an older population.

23.552 **Humans alter their priors by using information from their recent past**

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Statistical regularities in the occurrence of environmental properties are useful to consider in many tasks. The representation of such regularities by the nervous system can be modeled as a prior distribution. Such a prior could represent all past experience with that property. For changing environments, however, it may be useful to inculcate recent information into the prior. One factor that influences the rate of change of a prior is the time over which the nervous system considers past information while tracking environmental changes. We performed a study to obtain an estimate of the state of the prior in a task for which the statistics of the environment change unexpectedly. Participants reached across a tablet to hit a target that moved along a fixed path to a specified location in space. The time the target took to reach the specified point of interception was normally distributed within blocks of 83 trials. The mean time differed between blocks (660 or 885ms) but the standard deviations were identical (73.5ms). While the target was visible in most trials, in some trials it disappeared 72ms after its appearance. Participants were instructed that they may not see the target in some trials but they should nevertheless attempt to intercept it as if it were moving invisibly. We treat the participants' response times on such catch trials as an estimate of their prior. We model the response times of the catch trials using a Kalman filter with a time-window that recalculates the gain as the experiment progresses. We compare the squared residuals to those obtained from a model that uses an optimal fixed gain (Kalman 1961, Burge et al. 2008). The Akaike's information criteria indicate that the model with an optimal window is three times more likely to be correct.

Acknowledgement: The research leading to these results has received funding from the European Community's Seventh Framework Programme FP7/2007-2013 under grant agreement number 214728-2

23.553 **Misattribution of unconscious visuo-motor conflict to preferential decision**

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It is well known that one's preference is facilitated or impeded due to misattribution of a prior cognitive event as shown in priming, framing, or orienting behavior. Here we report the initial finding that misattribution occurs even due to a visuo-motor conflict. Twenty subjects were asked to choose a preferred face out of the two faces, presented on the left and right sides of a central fixation point, by moving a joystick leftward or rightward. In the background, task-irrelevant random dot motion (moving leftward, rightward, or vertically) was presented at one of six coherence levels (0, 5, 10, 20, 50, 100%). According to subjects' choice, trials were classified into the three types: a congruent trial (the direction from the fixation point to the chosen face matched the direction of task-irrelevant motion), an incongruent trial (the two directions were opposite), and a baseline trial (the two directions were perpendicular). Results indicate that only when task-irrelevant motion was subliminal (5% coherence), the number of the congruent trials was significantly larger than that of the incongruent trials. Following each choice, the subjects were asked to rate their relative preference for the chosen face on a five-point scale. The relative preference was significantly higher in congruent trials than in incongruent trials only when subliminal motion was presented. In addition, the relative preference was significantly impeded when a subliminal motion direction was opposite to a response direction but was not facilitated when these directions were the same. Taken together with results of further experiments, we conclude that when

a conflict between directions of motor response and task-irrelevant motion is not consciously noticed, it can be misattributed to preferential decision. Moreover, unlike the misattribution of a prior cognitive event that can facilitate or impede preference, visuo-motor misattribution only impedes preference but do not facilitate it.

Acknowledgement: This study is funded by grants from NFS (BCS-0549036) and NIH (R01 EY 015980, R01 EY019466, R01 AG031941, R01 MH091801) to T.W. K. S. was supported by the Uehara Memorial Foundation. Portions of the research in this paper use the FERET database of facial images collected under the FERET program, sponsored by the DOD Counterdrug Technology Development Program Office. We thank CVL and CV, PTER, Velenje for granting permission to use their face database and Kou Murayama and Hisato Imai for their comments on the earlier version of our study.

23.554 **When perceptual- and cognitive decisions are excellent - mostly.**

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Lower level decisions involving the perceptual and perceptuo-motor systems (e.g., choosing an aim point for a hand movement) appear near-optimal. High level decisions (e.g., choosing between financial options), on the other hand, are commonly described as sub-optimal. In most studies, however, methods differ between investigations of perceptual and cognitive decision making. To facilitate comparison, we studied both in a common context: deciding how much time to spend on a task. Our experiments involved measuring time-accuracy relationships and a decision stage. In the latter, observers were given a limited amount of time to complete an unspecified number of trials. They faced a choice of completing many trials with low accuracy, or completing fewer trials but with a higher accuracy. Observers were told the values of correct and incorrect responses, were paid a performance related bonus, but received no feedback. To assess performance, we mapped observers' choices onto efficiency functions derived from the independently measured time-accuracy relationships. When the underlying task was perceptual (motion discrimination) observers made highly efficient decisions. Moreover, performance was excellent whether the task was easy or hard. Apparently, people have good knowledge of their task performance and use it to make highly efficient decisions. For asymmetric reward structures people changed their behaviour in a qualitatively appropriate manner (e.g., slowed down), but did not behave in a quantitatively appropriate manner (slowed down by the right amount). With baseline perceptual performance established, we explored cognitive performance (mental arithmetic & mental rotation) under a symmetric reward structure. Performance was virtually indistinguishable from perceptual performance. Finally, we obtained excellent perceptual- and cognitive performance even when task difficulty changed unpredictably from trial to trial. The results may be interpreted as optimisation of actions, rather than specific sub-systems, in an uncertain environment.

Acknowledgement: Andreas Jarvstad was supported by the ESRC, UK

Development: Infancy and childhood

Saturday, May 7, 2:30 - 4:15 pm

Talk Session, Royal Palm 1-3

Moderator: Melanie Palomares

24.11, 2:30 pm

Reciprocal structural relationship between primary sensory and prefrontal cortices in the human brain

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Brain structure shapes cognitive functions and constrains behaviors, but varies remarkably across human individuals even for the earliest sensory cortices. To understand the topographic principles of such cortical variability, we investigated whether the volume of functionally defined primary visual cortex predicted that of other cortical structures. In a large sample of healthy participants, the gray matter volume of primary visual cortex correlated positively with that of primary auditory cortex, but negatively with focal areas of anterior prefrontal cortex. These structural relationships were specific to primary visual cortex (V1) and not observed for associated visual cortices V2 or V3. Moreover, the retinotopically ventral (representing the upper visual field map) and dorsal (representing the lower visual field map) halves of V1 shared variation with the corresponding but not the opposite halves of V2, V3, and exhibited focal negative correlations with ventromedial and dorsolateral areas of anterior prefrontal cortex respectively. Our study revealed a structural trade-off between primary sensory and prefrontal cortices that arises from two separated anatomical pathways. This intriguing and hitherto unknown topographical organization of human cortex is likely to be regulated by genetic or developmental mechanisms and may be the basis of inter-individual behavioral differences in basic sensory versus high-order cognitive processing.

Acknowledgement: This work was supported by the Brain Research Trust (CS), JSPS (RK) and the Wellcome Trust (GR, DSS).

24.12, 2:45 pm

Locating 'dorsal stream vulnerability': high-density global motion and form coherence VEPs related to MRI in infants born very preterm

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In typical development, infants' global motion responses are located more laterally (MT?) compared to the dominant occipital midline focus in adults, indicating developmental reorganization of cortical motion networks (Wattam-Bell et al, *Current Biol*, 2010). In infants born very preterm (≤ 32 weeks gestational age), VERP and behavioural visual cortical indicators (orientation selectivity and attention shifts) correlate with structural MRI measures of brain damage and predict later neurocognitive outcome (Atkinson et al, *Arch Dis Child* 2008). In later childhood, functions associated with the dorsal stream (e.g. motion coherence thresholds) are particularly vulnerable in preterms and children with specific neurodevelopmental disorders e.g. Williams syndrome, autism (Atkinson & Braddick, *Prog Brain Res* 2007; Braddick et al, *Neuropsychologia*, 2003).

Here we study form and motion responses in preterm infants (N=22) at 5 months post-term age. Activation by global form and motion coherence (taken as signatures of extra-striate ventral- and dorsal-stream areas) was mapped using a high-density geodesic sensor array, and compared with detailed analysis of term-equivalent- MRI, scoring 20 identifiable anatomical markers for abnormality (e.g optic tract, putamen, extrastriate, occipitoparietal) alongside behavioural tests of acuity, binocularity, fields, accommodation, attention shifts. Preterm infants with MRI scores indicating severe brain damage (e.g cystic PVL) showed absent or poor global motion

responses compared to either global form or local contrast. Those with mild/moderate MRI scores (e.g. no optic tract damage but minor extrastriate abnormality) showed reliable global motion responses, but with a more immature distribution, showing isolated lateral foci of activation compared to term-born controls.

We conclude that, in line with evidence in later childhood for 'dorsal stream vulnerability', perinatal risk factors affect global motion responses in infancy more than static form. Even relatively healthy preterm infants (mild/moderate group) show immaturity in the developmental reorganization of cortical motion areas, which may be an early signature of a developmental motion processing deficit.

Acknowledgement: Medical Research Council, the Garfield Weston Foundation, and Wellbeing NIHR Biomedical Research Centre funding scheme.

24.13, 3:00 pm

Protracted Development of Texture-defined Figure/Ground Segmentation: A High-Density ssVEP Study

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In order to segment figures from their backgrounds it has long been known that our visual system uses the texture information at object borders that is produced by discontinuities along features such as orientation or color (Nothdurft, 1985a-b, 1993, 1994). Nevertheless, the neural basis of texture segmentation remains unclear. Recent studies, however, suggest that this task elicits responses in V1 along with a cascade of feedforward and feedback responses across the visual hierarchy (Thielscher, 2008; Hupe, et al, 1999). To study the developmental trajectory of the neural mechanisms involved in texture-defined figure/ground segmentation and their modulation by attention, we recorded high-density visual evoked potentials (VEPs) in children (6-10 years), teens (13-15 years) and in adults (18 and above) to synthetic images portraying simple texture-defined figures. The VEP elicited by the appearance of a texture defined shape had a peak response appearing at about 157 ms for children, 131 ms for teens and 115 ms for adults. Scalp topographies of the peak responses show spatially constrained activity in medial areas in children while these peak responses are progressively more lateral in teens and adults. Even in teens the location of the peak responses on the scalp does not match the adult pattern. This difference in topography, combined with the faster response latency in adults as compared with teens, suggests that there is a protracted development of the cortical areas underlying texture-defined shape segmentation.

Acknowledgement: Promising Investigator Research Award

24.14, 3:15 pm

The interaction between chunking and stimulus complexity in infant visual statistical learning

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Human infants are known to learn statistical regularities of the sensory environment implicitly in various perceptual domains. Visual statistical learning studies have illustrated that this learning is highly sophisticated and well-approximated by optimal probabilistic chunking of the unfamiliar input. However, the emergence and unitization of such perceptual chunks at an early age and their relation to stimulus complexity have not been investigated before. This study examines how 8-month-old infants can extract statistical relationships within more complex, hierarchically structured visual scenes and how unitization of chunks is linked to familiarity performance. In the first experiment, infants were habituated to quadruplet scenes composed of a triplet of elements always appearing in the same relative spatial arrangement and one noise element connected to the triplet in various ways. After meeting a criterion of habituation, in each of several test trials, infants saw one original triplet and a new triplet containing a rearrangement of familiar elements. Contrary to earlier results obtained with pairs rather than triplets, infants did not show a significant preference

for either test stimulus ($N=20$, $p>0.9$). In a second experiment, infants were habituated using the same quadruplet scenes, but during the test, they saw one of the habituation quadruplets, and a second quadruplet in which the associated noise element was switched with a noise element from another triplet. Infants that habituated ($N=13$) to the familiar quadruplet looked longer to the novel quadruplets, indicating they can recognize a change of one single element ($p=0.026$), whereas non-habituating infants ($N=9$) showed no preference ($p>0.9$). These results suggest that as stimulus complexity increases, infants' ability to learn and unitize chunks becomes limited, even though they are perfectly able to encode the structure of the scene. Apparently, unitization and the ability to use embedded features in more general contexts emerge after encoding itself is already operational.

24.15, 3:30 pm

Face- and object-selective cortical responses in 4- to 6-month-old infants and adults.

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Studies of anatomical changes in early brain development have provided evidence of a hierarchical progression in which primary sensory areas mature first and prefrontal cortex matures last. Whether these sequential structural and physiological changes directly limit the emergence of complex stimulus specificity and the functional specialization of cortical areas is not known. In the present study we recorded high-density, steady-state visual evoked potential responses to intact and scrambled images of objects (Kourtzi and Kanwisher, 2000) and comparable images of human faces, both of which are known to activate areas within lateral occipital cortex in adults. We compared two conditions: alternating (1 Hz) scrambled versus intact pairs of images which maintained the same low-level properties, but differed in global configuration, and alternating scrambled-scrambled pairs which were equated in low-level properties. A difference in the response waveform between these two conditions was used to isolate object- and face-selectivity. Such selectivity was found in both infants and adults for both object categories. However, adults showed a larger response to the onset versus the offset of both object and face images, but infants showed a larger onset response only to faces. Object responses in infants were dominated by offset rather than onset responses and the onset response was weak and delayed for objects compared to that for faces. The topographies of the adult onset responses to objects and faces were both bilaterally symmetric over lateral occipital cortex and were also present over frontal cortex. In contrast, the infant responses were restricted to medial and lateral occipital electrodes, and were not found over frontal electrodes. These findings demonstrate that while at least a basic form of selectivity is present in 4- to 6-month-old infants for both objects and faces, the qualitative pattern of responses to faces is more mature than that of objects.

24.16, 3:45 pm

On the development of human face-processing abilities: Evidence for hyperactivation of the extended face system in children

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Multiple regions in the human brain respond preferentially to visual face stimuli. Functionally, these regions are organized around a "core" system primarily responsible for perceptual analysis, and an "extended" system associated with non-visual functions related to emotional, semantic, and dynamic analysis of faces. Recent evidence suggests that some of these regions, specifically in the core system, undergo protracted development extending into adolescence; however, few studies have examined the development of face-processing systems using whole-brain measures. Here, we report functional MRI findings from 30 children (6-12 years), 20 adolescents (13-16 years), and 21 adults (18-40 years) tested in a simple blocked-design viewing task for faces, diverse objects, watches, and scrambled stimuli (i.e., localizer task). A region of interest (ROI) analysis focused on the right fusiform face area (rFFA), the area within the fusiform gyrus where a Faces>Objects contrast was significant ($p < 0.005$). Consistent with

recent reports using visual recognition paradigms, FFA volume showed a linear increase with age. Regression analysis of whole-brain BOLD signal intensity showed a positive correlation of age within the right occipital face area (OFA). Thus, two primary components of the core system were positively correlated with age. In striking contrast, children produced significantly greater activation relative to adults in multiple regions outside of ventral occipital-temporal cortex, specifically in regions within the extended system, including bilateral amygdala, precuneus, and inferior frontal gyrus. The findings indicate that a prolonged developmental trajectory is observed in other face preferential regions in addition to areas in the core system. More critically, the activation patterns suggest that children do not modulate activity within the extended system during simple face viewing whereas adults limit face-preferential processing to regions in the core system. Thus, modulation of activation to faces must be a key component in perceptual development.

Acknowledgement: NIH/NICHD R01 HD060595

24.17, 4:00 pm

Development of Visual-Motor Integration: The Role of Genetic & Environmental Factors

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BACKGROUND. Integrating visual information and motor actions, Visual Motor Integration (VMI), is necessary to perform tasks as simple as picking up a spoon and as complex as writing. Despite VMI's importance and the fact that VMI is impaired in genetic disorders such as Williams Syndrome (see Georgopolous et al., 2004) and Shwachman-Diamond Syndrome (see Kerr et al., 2010), little is known about the role of heritable and environmental factors in typically-developing children's VMI.

METHODS. We tested 125 pairs of typically-developing twins who were between 3 and 12 years old. As is typically done, VMI was assessed via a figure-copying task. Our test was modeled after the Beery-Buktenica Test (2004) and had 6 figures (see Figure 1). Each figure was assessed along 4 dimensions, with each dimension scored on a 1 to 5 scale.

RESULTS. Age was highly correlated with total copying score ($r = .83$, $p < .00001$, see Figure 2). Heritable factors accounted for 78% of the variance in 3- and 4-year olds' copying scores and 98% of the variance in 5- and 6-year olds' copying scores. In striking contrast, heritable factors explained little or none of the variance in older children's copying scores.

DISCUSSION. One possible explanation is that VMI does have a strong genetic component for typically-developing children's VMI skills. However, because schools explicitly teach children how to copy letters, numbers and shapes, as children get older, the impact of environmental factors such as quality of instruction swamps the impact of heritable factors on copying. If this account is correct, other non-copying measures of VMI could yield substantial heritabilities for both younger and older children. A second possible explanation is that genetic factors influence the rate of development of VMI abilities, but not the level of VMI ability eventually obtained.

Acknowledgement: NSF BCS-0446850

Eye movements: Remapping

Saturday, May 7, 2:30 - 4:15 pm

Talk Session, Royal Palm 4-5

Moderator: Martin Rolfs

24.21, 2:30 pm

Spatiotemporal remapping during saccades revealed by classification images analysis.

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It is well known that saccades cause profound transient effects to the receptive fields of parietal cortical cells and also to human perception. Using the "agnostic" psychophysical tool of Classification Image Analysis, we measured the dynamic changes of the spatio-temporal impulse response

function of perceptual mechanisms at the time of saccades. Three subjects detected (in 2AFC) the presence of a near-threshold white bar briefly flashed (21 ms) on a $24^\circ \times 1.5^\circ$ strip of dynamic white noise at different times from the onset of a 18° voluntary saccade. We computed the mean kernel of activation of the perceptive field for bars presented at different times before or after saccadic onset. Well before or well after the saccade, we reproduce the well known spatio-temporally separable perceptive field that extended over about 6° and 60 ms. Just before saccades, the spatial-temporal spread of the perceptive field increased to 12° by 120 ms; and more importantly, the function became oriented in space-time. At saccadic onset, the kernel presented two distinct foci, one at -45 ms the other at 50 ms after saccadic onset. These two foci correlate well with the temporal distortions known to occur around the time of saccades (Binda et al, J. Neurosci., 2009). The interval between the two foci shows a strong suppression of the signal, with a time course similar to the known dynamics of saccadic suppression. These data provide direct support for the existence in the human brain of remapping of neuronal receptive fields at the time of saccades. They further support the suggestion that receptive fields become transiently oriented in space-time around the time of saccades allowing trans-saccadic integration of pre- and post-saccadic visual signals.

Acknowledgement: This study has been funded by the EC project STANIB (FP7-ERC).

24.22, 2:45 pm

How transient "remapping" of neuronal receptive fields mediates perceptual stability

David Burr^{1,2}(dave@in.cnr.it), Marco Cicchini^{1,2}, Paola Binda², Concetta Morrone³; ¹Department of Psychology, University of Florence, ²CNR Neuroscience Institute, Pisa, ³Department of Physiological Sciences, University of Pisa

It is well known that saccades cause transient but profound changes to the receptive fields of parietal cortical cells and also to human perception. It remains unclear, however, how these events contribute to stability. One critical but largely overlooked fact is that as receptive fields shift, responses to the "new receptive field" are delayed in time, creating a receptive field oriented in space-time (Binda et al., J. Neurosci., 2009). We studied mislocalization of pairs of bars (6×1 deg, one white, one black) briefly presented successively (temporal separations 20 - 160 ms) at the same or different positions, at various times relative to the onset of a 20° horizontal saccade. Single perisaccadic bars, and also pairs of bars of different orientation, were strongly mislocalized, by up to half saccade amplitude. However, when the bars were of the same orientation and displayed within 40 - 120 ms of each other, no mislocalization occurred with either, provided at least one bar was presented outside the crucial interval ± 20 ms from saccadic onset. The stabilization occurred only for bars nearby in external space (within 5°) even though the separation on the retina could be over 20° . There was also a strong compression of apparent time. We modeled the interaction between the bars with a neuronal mechanism extending over space and time that responds to both stimuli: as the response to the bar displayed to the "future receptive field" is delayed, it arrives simultaneously with the response to stimuli displayed later to the classic receptive field, and are therefore fused. This transient perisaccadic space-time orientation of the future receptive field generates a response profile that is broad, but anchored to external space, and this is the key to perceptual stability.

Acknowledgement: European Research Council

24.23, 3:00 pm

Saccade target visible on landing despite removal: Can human observers see the prediction generated by presaccadic remapping?

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Just before a saccade certain cells (found for instance in LIP, SC and FEF in monkeys) are activated by stimuli presented at the location that will fall in their receptive field after the saccade is made. It has been proposed that this remapping contributes to a prediction of the postsaccadic visual detail that is compared with the actual one. Based on the difference between the prediction and the input, the visual system realigns the relation between retinal and world coordinates (Deubel & Bridgeman). We examined the visibility of this predicted transsaccadic visual image by removing the saccadic target before the saccade and asking participants to report if they had looked directly at the target. The participants ($n = 19$) first fixated a cross presented at the center of the screen. After an unpredictable interval, a flash

presented in the periphery, indicated where they should move their eyes. At various times after the saccadic cue, a vertical bar was presented at the target location for 30ms. The participants' task was to report if they looked directly at the bar. We found that even when the bar disappeared as long as 170ms before the saccade -- and was therefore never presented in the fovea -- participants reported that they did look at it directly on average 85% of the time ($+/-8.3\%$). Those results suggest that when observers saccade to a target that disappears before the end of the saccade, they see the target as if it was still there when their eyes land.

Acknowledgement: NIH

24.24, 3:15 pm

Mapping of presaccadic receptive field profiles in the macaque frontal eye field

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The receptive fields (RFs) of neurons in many areas of the primate visual system are altered immediately prior to the initiation of saccadic eye movements. However, the exact nature of those RF dynamics is unknown. Typically, the dynamic changes of RFs have been inferred on the basis of only a few visual stimulus positions rather than from detailed spatial profiles of presaccadic RFs. We measured detailed RF profiles of frontal eye field (FEF) neurons by probing a large number (>72) of stimulus positions within a large portion of visual space in the contralateral hemifield. RF profiles were obtained both during passive fixation (fixation trials) and immediately prior to the initiation of visually guided saccades (presaccadic trials). On both types of trials, we recorded the responses of FEF neurons to probe stimuli ($1^\circ \times 1^\circ$ white squares) briefly flashed (~ 20 ms) at random positions. On fixation trials, multiple positions were probed in succession at 0.5 Hz and the monkey was rewarded for maintaining fixation throughout the trial. On each presaccadic trial, the monkey was rewarded for making a saccade to a visual target ($0.5^\circ \times 0.5^\circ$ red square) in the contralateral hemifield and a single position was probed within 100 ms of saccade initiation. Thus far, we find clear presaccadic changes in the RF profiles of FEF neurons. In particular, we observe that presaccadic RFs move toward the saccade endpoint in a direction nonparallel to the saccade vector.

24.25, 3:30 pm

Saccadic adaptation fields have a visual component anchored in spatiotopic coordinates

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The oculomotor system compensates for errors in saccades by a dynamic adaptive process that involves both the motor system and visual representation of space. To study the interaction between the visual and motor representations we designed a saccadic adaptation paradigm where the two representations were in opposite directions. We adaptively increased saccadic amplitudes for rightward saccades (outward adaptation), then measured the landing point for leftward saccades aimed at a target in the same spatial location as that used during adaptation training. These leftward saccades decreased rather than increased in amplitude, to land in the same spatial position as during adaptation, implicating visual signals play a part in saccadic error correction. To examine the coordinate system of the visual signals, we designed a memory double-saccade task that dissociated retinal from spatiotopic coordinates. When the second saccadic target was presented to the same spatial but different retinal position, saccade landing showed strong adaptation; but when presented to the same retinal but different screen position, saccade targeting was unaffected by adaptation. These results suggest that saccadic adaptation fields are strongly influenced by the position of the target in the external world; and conversely, saccadic adaptation changes the memory representation of the visual field, which is encoded in spatiotopic coordinates.

Acknowledgement: This study has been funded by the EC project STANIB (FP7-ERC).

24.26, 3:45 pm

Visual attention in the pre-saccadic intervalSebastiaan Mathôt¹(s.mathot@psy.vu.nl), Jan Theeuwes²; ¹Dept. of Cognitive Psychology, Vrije Universiteit, Amsterdam

The moment just before an eye movement is a turbulent time for the visual system, and for visual attention in particular. A number of competing theories have been proposed that aim to provide a unifying account of pre-saccadic processes. According to the “remapping” hypothesis, visual information is transferred within retinotopic maps to compensate for eye movements. Remapping is believed to be “predictive” (i.e., starting before the onset of a saccade; Mathôt & Theeuwes, 2010, *Exp. Brain Res.*) and to last for some time after an eye movement has ended (Mathôt & Theeuwes, in press, *Psychol. Sci.*). However, there are at least two alternative frameworks, which account for much of the same data in a very different way. Hamker, Zirnsak and Lappe (2008, *PLoS Comp. Biol.*) have proposed a model based on receptive field shifts towards the saccade target. Cavanagh, Hunt, Afraz and Rolfs (2010, *Trends. Cogn. Sci.*) have suggested that the visual system anticipates which retinal locations will be relevant after a saccade, and that “attention pointers” are shifted towards those locations. This differs from the remapping hypothesis in that visual features, such as color, are not remapped. To resolve the current debate on pre-saccadic processes, we have investigated pre-saccadic attentional effects in more detail and found a number of surprising results. For example, just before the execution of a saccade, we found a small attentional effect in the direction opposite from the saccade target. Although none of the frameworks would a-priori predict this result, a tentative explanation can be offered in terms of shifting attention pointers, or, analogously, predictive remapping of attention. We discuss the implications of this result for existing theories of pre-saccadic processes.

Acknowledgement: NWO (Netherlands Organization for Scientific Research), grant 463-06-014 to Jan Theeuwes

24.27, 4:00 pm

Saccades gradually increase the perceived contrast of their targetsMartin Rolfs¹(martin.rolfs@nyu.edu), Marisa Carrasco¹; ¹Department of Psychology, New York University, New York City, NY (USA)

The preparation of saccadic eye movements results in pronounced shift of spatial attention to their targets, alerting corresponding locations in early visual cortices and locally improving visual performance as time progresses towards the movement. Here, we show that these attention shifts also lead to a remarkable change in the visual appearance of stimuli presented at the location of the movement goal. Participants fixated a central spot while two standard stimuli (Gabor patches) were flashed in the visual periphery, left and right of fixation. Shortly afterwards, a central movement cue instructed participants to quickly generate a saccade to one of the two stimulus locations. During the latency of the saccade, that is, after the movement cue but before the saccade was actually executed, a test stimulus was flashed at the movement goal. The test stimulus differed from the standard in contrast and, after the execution of the saccade, participants judged this difference in a two alternative forced-choice task, allowing for the assessment of changes in perceived contrast across the time course of saccade preparation. The data show that as time approached the saccade, the test contrast necessary to equate the standard (point of subjective equality) decreased substantially. These results suggest that saccade preparation, like covert attention, alters early visual processing in a way that is similar to increasing the signal strength, revealing perceptual correlates of feedback signals from eye-movement control areas to visual cortex.

Perception and action: Navigation and locomotion

Saturday, May 7, 5:15 - 6:45 pm

Talk Session, Royal Palm 1-3

Moderator: Simon Rushton

25.11, 5:15 pm

The relationship between perceived straight-ahead and walking direction.Tracey A. Herlihey¹(tracey.herlihey@utoronto.ca), Simon K. Rushton¹, Cyril Charron²; ¹School of Psychology, Cardiff University, ²School of Engineering, Cardiff University

If an error is injected into the perceptuo-motor loop between the eye and the foot an observer will walk to a target along a curving trajectory. Over time, the trajectory will straighten. Over the same period, the observers' perception of egocentric direction will also change. What is the relationship between the two changes? Does a change, or recalibration, of perceived direction account for the change in trajectory? Our hypothesis was that it does. Specifically we hypothesised that a change in perceived visual direction is responsible for the changes in trajectory. We explored this possibility by injecting a small error into perceived egocentric direction using prisms, and measured trajectory and perception of egocentric direction (visual and proprioceptive) at several time points (after 6, 12 and 24 walking trajectories). In line with our hypothesis, we found that the change in walking trajectory was directly related to the change in perceived visual direction (visual shift), but not felt direction (proprioceptive shift). We were then able to subject our hypothesis to a challenging test: we observed that there appeared to be a marked asymmetry between the visual shifts that resulted from use of leftward displacing prisms and rightward displacing prisms. If our hypothesis was correct, this asymmetry should be reflected in the trajectory data. A corresponding asymmetry in the trajectory data was indeed found. Thus, we conclude that a change in perceived visual direction accounts for the change in trajectory.

Acknowledgement: EPSRC

25.12, 5:30 pm

Rapid recruitment of extra-visual information supports heading control when visual feedback is unavailableSteven Cloete¹(scloete@hms.uq.edu.au), Guy Wallis^{1, 2}; ¹School of Human Movement Studies, University of Queensland, ²Queensland Brain Institute, University of Queensland

Regulation of egomotion has become a classical test bed for models of visually-guided behaviour. Much of this work has involved removing access to vision prior to movement execution. Work conducted in fixed-base and moving-platform driving simulators (e.g. Cloete & Wallis, *Experimental Brain Research*, 2009), has revealed that in the absence of visual feedback, participants commit highly systematic errors when attempting complex steering movements (such as lane changes and obstacle avoidance). These errors are consistent with a broad misunderstanding of steering dynamics, which leads to a startling inability to predict the effect of steering wheel manipulations on the trajectory described by the vehicle. Although informative, studies of this type test behaviour in a context quite unlike that which we experience in our everyday lives, because they involve the absence of sustained inertial forces. As a result, the contribution of other sensory systems (e.g. vestibular, somatosensory and proprioceptive) has been largely ignored. In the experiments reported here, we studied behaviour in a moving vehicle, which allowed us to assess the role of these non-visual cues. Participants were required to undertake lane-change manoeuvres on a 10,000sqm asphalt skidpan, with sustained visual occlusion achieved with a pair of LCD shutter goggles. Without visual feedback, participants initially produced large and systematic errors in heading similar to those found in previous studies. However, over the course of only 10 trials they were producing the correctly integrated sequence of steering wheel movements. The results suggest that extra-visual feedback can be rapidly recruited to produce successful execution of complex steering movements. Curiously, despite the improved performance, the majority of our subjects revealed no improvement in their insight into how to conduct a lane change. The results carry a number of implications for theories of dynamic re-weighting in multisensory integration.

Acknowledgement: Human Frontiers Science Projects RGP 03/2006

25.13, 5:45 pm

Visual and non-visual contributions to the perception of object motion during self-motionBrett Fajen¹(fajenb@rpi.edu), Jonathan Matthis¹; ¹Cognitive Science Department, Rensselaer Polytechnic Institute

When one moves in the presence of other moving objects, optic flow includes a component due to self-motion and a component due to object motion. Contrary to established theories of interception and obstacle avoidance, selecting actions and guiding locomotion relative to moving objects requires the visual system to recover the object-motion component. Formally, this can be achieved by using visual and/or non-visual self-motion information to discount the influence of self-motion, such that the remaining component is entirely due to object motion. Previously, we demonstrated the contribution of non-visual self-motion information in recovering the object-motion component (Fajen & Matthis, submitted). In this study, we directly tested the contribution of visual self-motion information. Two experiments were conducted in an immersive virtual environment viewed through a head-mounted display. In Experiment 1, subjects walked toward a gap between a pair of converging obstacles, and were instructed to judge before reaching the gap whether they could safely pass through it. On a small percentage of catch trials, the visual gain was increased such that subjects moved relative to the stationary background 50% faster than normal. Their movement relative to the obstacles was not affected. Subjects were more likely to judge gaps as impassable on catch trials, demonstrating the influence of visual information about the magnitude of self-motion on the perception of object motion. In Experiment 2, we tested the influence of visual information about the direction of self-motion by manipulating subjects' direction of movement through the virtual environment. As in Experiment 1, this manipulation did not affect subjects' movement relative to moving obstacles. Judgments were again consistent with an influence of visual self-motion information. Taken together with previous research, the findings suggest that people rely on both visual and non-visual self-motion information to recover information needed to guide locomotion relative to moving objects.

Acknowledgement: NIH R01 EY019317

25.14, 6:00 pm

Gazing at tangent point location during curve driving does not avoid foveal motion and leads to optokinetic nystagmus.Colas Authié¹(colas.authie@gmail.com), Daniel Mestre¹; ¹Institut des Sciences du Mouvement, CNRS et Université de la Méditerranée, France

Many studies have shown that during curve driving, the drivers have gaze fixation patterns in the vicinity of the tangent point (TP), this latter being the intersection between the inside edge of the road and its tangent passing through the driver position. The interest for the TP is mainly due to the fact that on one hand, its angular position is linked to the road curvature and therefore can be a control variable for the driver; and, on the other hand, it may correspond to a minimal speed in the optical flow. However, the TP is only motionless when the trajectory precisely follows the curve's geometry. In the present study, we measured gaze behavior during curve driving, with the general hypothesis that gaze cannot be stable when exposed to a global optical flow due to self-motion. We used a driving simulator coupled to a gaze recording system. Ten participants drove on a track composed of eight curves of various radii. Results show that gaze position is, as previously described, located near the TP. In addition, we observe the presence of a systematic optokinetic nystagmus (OKN) around the TP position. The OKN slow-phase direction does not match the foveal optic flow direction, while slow-phase speed is about half the local speed. When averaging the flow on larger areas, gaze and flow directions match better, and gaze and flow speeds are optimally matched for an optic flow integration over two degrees. We thus confirm that the TP is a privileged feature in the dynamic visual scene during curve driving. However, studying only gaze fixation is not fully relevant, because the TP is surrounded by optic flow, whose global characteristics induce retinal drifts and lead to OKN behavior. We consider that this must be taken into account for future models of vehicle control.

25.15, 6:15 pm

Distinct neural networks underlie encoding of categorical versus coordinate spatial relations during active navigationOliver Baumann¹(o.baumann@uq.edu.au), Edgar Chan¹, Jason B Mattingley¹; ¹Queensland Brain Institute & School of Psychology, The University of Queensland

It had been proposed that spatial landmarks are encoded either categorically, such that the relative positions of objects are defined in prepositional terms (e.g., to the left/right, in front/behind); or in terms of visual coordinates, such that the precise distances between objects are represented. In humans, it has been assumed that categorical representations are subserved by a left hemisphere neural network, whereas coordinate representations are largely right-lateralized. However, evidence in support of this distinction has been garnered almost exclusively from tasks that involved static, two-dimensional arrays (e.g., objects arranged on a table-top), rather than in the context of active navigation. In the present study, we used functional magnetic resonance imaging (fMRI) to identify neural circuits underlying categorical and coordinate representations during active spatial navigation of a virtual environment. In the encoding phase of each trial, participants navigated to the location of a target object and encoded either its spatial quadrant relative to a reference landmark (Categorical condition) or its distance from a reference landmark (Coordinate condition). After a short delay, participants re-entered the arena and were required either to navigate back to the appropriate quadrant of the arena, disregarding their distance from the landmark, or to navigate to an appropriate distance from the landmark ignoring the quadrant. We examined fMRI activity patterns during the encoding period, in which visual exposure to the virtual environment was matched across conditions. Activity in the categorical versus coordinate condition was significantly greater in the posterior and medial parietal cortex bilaterally, and in the left middle temporal gyrus. The complementary contrast (coordinate minus categorical) revealed greater activity in the right hippocampus, parahippocampus and dorsal striatum. These findings are broadly consistent with analogous studies in rodents, and support the suggestion of distinct neural circuits underlying categorical and coordinate representations of object location during active spatial navigation.

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25.16, 6:30 pm

A new neural framework for visuospatial processingDwight Kravitz¹(kravitzd@mail.nih.gov), Kadhambatcha Saleem², Chris Baker¹, Mortimer Mishkin²; ¹Laboratory of Brain and Cognition, National Institute of Mental Health, National Institutes of Health, ²Laboratory of Neuropsychology, National Institute of Mental Health, National Institutes of Health

The division of cortical visual processing into functionally and anatomically distinct dorsal and ventral streams is a key component of theoretical frameworks guiding visual neuroscience. The characterization of the ventral stream as a 'what' pathway, contributing to the conscious representation of stimulus quality is relatively uncontroversial, but the nature of dorsal stream processing is less clear. Originally proposed as a 'where' pathway supporting spatial vision, more recent accounts have suggested it is a 'how' pathway, primarily supporting unconscious visually-guided action. Here, we synthesize anatomical, lesion, and functional evidence from human and monkey and propose that the dorsal stream actually gives rise to at least three distinct pathways: 1) parieto-prefrontal, 2) parieto-premotor, and 3) parieto-medial temporal, supporting eye movements and spatial working memory, visually-guided actions of the body (e.g. arm), and navigation, respectively. The anatomical and functional properties of the parieto-medial temporal pathway have not been well-characterized previously. The pathway courses medially, through the posterior cingulate and retrosplenial cortices, providing complex spatial information to the medial temporal lobe. The functional properties of the cortical areas along this pathway are consistent with a role in navigation, specifically the coordination of primarily egocentric parietal representations and allocentric medial temporal representations of space. We argue that the presence of these multiple pathways render previous characterizations of the dorsal stream as a 'where' or 'how' pathway incomplete. These labels fail to capture the breadth or complexity of spatial processing occurring within the dorsal stream or the diversity of its projections. We propose a new neural framework for visuospatial processing, in which the occipito-parietal cir-

cuit comprising the dorsal stream functions as a general spatial processor, supporting, through its projections, a diverse set of conscious and unconscious spatial processing across many areas of cortex.

Acknowledgement: National Institutes of Mental Health Intramural Program

Object recognition: Parts and categories

Saturday, May 7, 5:15 - 6:45 pm

Talk Session, Royal Palm 4-5

Moderator: James Tanaka

25.21, 5:15 pm

Poselets: A distributed representation for visual recognition

Lubomir Bourdev^{1,2}(lboudev@eecs.berkeley.edu), Subhransu Maji¹, Jitendra Malik¹; ¹ECCS, U.C. Berkeley, ²Adobe Systems, Inc.

Detection and pose estimation of people in images are challenging tasks due to variations in articulation, viewpoint and appearance. Part detectors are a natural way to attack this problem, but identifying good parts remains an open question. Anatomical parts, such as arms and legs, are difficult to detect reliably because parallel lines are common in natural images. In contrast, a visual conjunction such as “half of a frontal face and a left shoulder” may be a perfectly good discriminative visual pattern. Bourdev and Malik [ICCV 2009] introduced new parts, called poselets, which correspond to such discriminative visual patterns. There is a wide variety of poselets -- a frontal face, a profile face, a head-and-shoulder configuration, etc. We discover them by choosing a random seed patch from the image of a random person in the training set and finding the “corresponding” patches in images of other people. A corresponding patch is defined as one that has the same spatial configuration of semantic keypoints (such as joints, eyes, nose) as the seed patch. We discriminatively train detectors for these patches. To find people in a test image, we evaluate the poselet detectors at multiple locations and scales and cluster the activations into person hypotheses. The activations within each cluster form a distributed representation of the pose of a person and provide the basis for numerous high-level vision tasks. Our system is the current best performer on the task of people detection and segmentation. We are able to infer attributes (the gender, style of hair, clothes, presence of glasses, hat, etc.) and actions (phoning, running, walking, reading a book, etc.) of people under arbitrary viewpoints and articulations. These ideas extend naturally to other visual categories. Interestingly, receptive fields of neurons in inferotemporal cortex have a variety consistent with that predicted by our model.

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25.22, 5:30 pm

View propagation in internal object memory representation

Tandra Ghose¹(tandra@berkeley.edu), Zili Liu²; ¹Department of Psychology, Technical University of Kaiserslautern, Germany, ²Department of Psychology, University of California, Los Angeles

Purpose. We investigated the way in which an object representation is encoded in order to allow recognition when the same object is later encountered from a different viewpoint. In particular, we investigated recognition when a canonical-view of the object was first seen, followed by a non-canonical-view of the same object; and vice versa. We also manipulated similarity between objects to study the degree to which this generalization was constrained by shape details. Finally, we manipulated experimental instructions to discourage view generalization, in order to assess the extent to which the view generalization was involuntary. Method. In Experiment-1, subjects rated the goodness-of-view resulting in our definition for canonical- and noncanonical-views for the subsequent experiments. Basic-level and subordinate-level objects were run in separate blocks for Experiment-2 (with viewpoint-independent object-based-recognition task) and Experiment-3 (with viewpoint-dependent image-based-recognition task). Each block had a study-phase (attractiveness-rating task) and a test-phase (recognition task). In study-phase half of the objects were shown in canonical-view and half in noncanonical-view. In test-phase old objects and equal number of novel objects were shown. For old-objects half images were in the same viewpoint as study-phase and the rest were in the other view. Results. In the object-based task, for basic-level objects, view generalization was perfect between canonical and noncanonical views. However, for subordinate-level objects, the generalization was limited. It was also signifi-

cantly better when the objects were first seen in a noncanonical-view and tested in a canonical-view, than the other way around. In comparison, in the image-based task and for basic-level objects, there was more involuntary generalization from noncanonical to canonical views. For subordinate-level objects, this generalization was comparable between canonical and noncanonical views. Conclusions. Results imply that in shape-representation, a view was less likely to be stored as a snapshot-template, but more likely to be involuntarily “canonicalized” in viewpoint-generalization.

25.23, 5:45 pm

Gaze Direction Representations in Human Superior Temporal Sulcus are Invariant to Head View

Johan D Carlin¹(johan.carlin@mrc-cbu.cam.ac.uk), Andrew J Calder¹, Nikolaus Kriegeskorte¹, Hamed Nili¹, James B Rowe^{1,2,3}; ¹Medical Research Council Cognition and Brain Sciences Unit, Cambridge, UK, ²Department of Clinical Neurosciences, University of Cambridge, Cambridge, UK, ³Medical Research Council Behavioural and Clinical Neurosciences Institute, Cambridge, UK

Humans are sensitive to the gaze direction of others, and use this visual information to guide attentional, emotional, and social processes. To accurately judge the direction of another’s gaze, it is necessary to represent not only the position of the eyes in isolation, but also the orientation of the head. Thus, gaze perception depends on an integrative process, where multiple combinations of head orientation and eye position produce the same gaze direction in a head-view invariant manner. We tested for such representations by applying a novel combination of multivariate searchlight mapping and correlation-based representational similarity analysis to human functional MRI data. A group analysis showed that response patterns in right anterior superior temporal sulcus (STS) extract a code for gaze direction in a manner that is not reducible to coding of the component head/eye cues in isolation (N=18, random effects. all $p < 0.05$, FWE-corrected for the anatomically-defined right STS region). Furthermore, this STS gaze direction code showed a graded similarity structure, with sensitivity to fine-grained distinctions between adjacent gaze directions. Our results show that anterior STS forms a late stage of social visual processing, where face features are integrated to form a perceptually-relevant gaze direction code. These findings exemplify how the representation of faces in anterior temporal regions becomes sensitive to perceptually-relevant dimensions, such as gaze direction, through invariance to intermediate-level features, such as head view.

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25.24, 6:00 pm

Recognizing objects, faces, and flowers using fixations

Christopher Kanan¹(chriskanan@gmail.com), Garrison Cottrell¹; ¹Department of Computer Science and Engineering, University of California San Diego

Most biologically-inspired and computer vision systems are purely feed-forward: they immediately classify an object after observing it, even if the model’s confidence is low. We have developed a biologically-inspired model called NIMBLE that actively classifies objects (Kanan & Cottrell, 2010). NIMBLE is based on two characteristics of the primate visual system: (1) sparse visual filtering and (2) sequential fixation-based visual attention. We learn sparse visual filters from natural image patches using Independent Component Analysis (ICA), which produces V1-like filters. The distributions of each ICA filter’s responses are fitted by generalized Gaussian distributions. Using these statistics, we compute a saliency map based on rare feature values (Zhang et al., 2008). In training, the saliency map is randomly sampled to generate simulated fixations, and NIMBLE records the responses of spatially pooled V1 features from the fixation region in a class-conditional non-parametric density model. In recognition, fixations are acquired the same way, and used to update a posterior probability distribution over the categories. We extract and store 100 fixations from each image in the training set, and use 100 fixations on test images. Although NIMBLE only uses one feature type, it exceeds state-of-the-art computer vision models when the number of training instances is small, and performs comparably with methods using four or more feature types (e.g., multiple kernel learning). NIMBLE achieves 78.5% mean per-class accuracy on objects (Caltech-101) using 30 training images per class (chance is 1/101), 92.7% accuracy on faces (AR) using one training image per person (chance

is 1/120), and 71.4% accuracy on 102 Flowers (chance is 1/102). We use the same parameter settings across datasets, demonstrating that NIMBLE, like primates, does not need to retune parameters for each problem.

Acknowledgement: This work was supported by the James S. McDonnell Foundation (Perceptual Expertise Network, I. Gauthier, PI), and the NSF (grant #SBE-0542013 to the Temporal Dynamics of Learning Center, G.W. Cottrell, PI and IGERT Grant #DGE-0333451 to G.W. Cottrell/V.R. de Sa.).

25.25, 6:15 pm

The Number Sense Follows the Object Sense

Lixia He¹(lxhe@cogsci.ibp.ac.cn), Tiangang Zhou¹, Jun Zhang², Yan Zhuo¹, Lin Chen¹; ¹State Key Laboratory of Brain and Cognitive Science, Institute of Biophysics, Chinese Academy of Science, ²University of Michigan, Ann Arbor, Michigan

Number sense is a capacity of cognition that apprehends the number of objects in a collection without invoking the requirement to refer to verbal symbols: We can 'see' how many objects presented, in a set, usually visually of up to about four (referred as subitizing) and can make an estimate of more than about four (Kaufman & Lord, 1949). Here, we showed that the perception of number is greatly determined by the perception of objects, where the 'notion' of an object [the holistic identity in the perspective of perceptual organization] could be precisely characterized as topological attributes (including connectivity and inside/outside relation). When some of the items were connected by a line or enclosed in a hollow figure, the total number of the items was underestimated directly proportional to the number of items connected or enclosed. Such a global topological effect in numerical perception is seen to be held independent of local features such as connecting form and item shape, and in a range of large and small numbers. Besides, topological effect decreased with the duration of stimulus presentation, revealing a possible early occurrence of topological perception in visual processing. Further functional Magnetic Resonance Imaging (fMRI) experiment revealed a similar pattern of neural activation for numerical distance effect and connectivity effect in human's intraparietal sulcus (IPS). The current series of studies suggests that numerical operation such as discrimination, estimation and enumeration may be based on knowledge of the perceptual objects themselves, defined by global topological attributes.

25.26, 6:30 pm

The neural correlates of self-identity: Own-face and own-object effects in event-related potentials

James Tanaka¹(jtanaka@uvic.ca), Lara Pierce², Lisa Scott³, Tim Curran⁴; ¹Department of Psychology, University of Victoria, ²Department of Psychology, McGill University, ³Department of Psychology, University of Massachusetts, ⁴Department of Psychology and Neuroscience, University of Colorado

Previous studies have shown that the observer's own face elicits speeded responses in behavioral tasks and generates a pattern of brain activity that is differentiated from other familiar stimuli. Studies employing event-related potentials (ERPs) have shown that when participants are monitoring for a novel target face, the presentation of their own face elicits an enhanced negative brain potential in posterior channels approximately 250 ms after stimulus onset. Here, we examine whether the own-face N250 effect generalizes to other self-referential objects, specifically, images of the participant's own dog and own car. In our experiments, participants were asked to monitor for a target face (Joe), a target dog (Experiment 1: Joe's Dog) or a target car (Experiment 2: Joe's Car). The target face and object stimuli were presented with non-target foils that included novel face and object stimuli and self-referential stimuli, the participant's own face, their own dog (Experiment 1) and their own car (Experiment 2). Our results showed that an enhanced N250 negative potential was elicited by the target face and the target objects relative to the novel non-target faces and objects. The time course for target faces and target objects differed. Whereas the N250 to the target Joe face accrued gradually, the N250 to the target Joe dog and Joe car was evident in the first block. Importantly, the participant's own face, own dog, and own car produced an N250 potential that was equal in magnitude to the target stimuli. Thus, similar to the ERP response to the participant's own face, self-referential objects evoked an N250 response that did not differ from recently familiarized faces and objects. These results support the prepo-

tency of self-relevant stimuli that readily command the observer's attention and spontaneously elicit an enhanced neural response that is independent of the stimulus' target status.

Acknowledgement: James S. McDonnell Foundation, the National Science Foundation (#SBE-0542013), the National Institutes of Health and the National Sciences and Engineering Research Council of Canada

Saturday Afternoon Posters

Color and light: Adaptation and constancy

Saturday, May 7, 2:45 - 6:30 pm

Royal Palm 6-8, Poster Boards 301 - 320

26.301 The strength of the McCollough effect does not increase linearly with saturation: implications for the cortical color code

Alan Robinson^{1,2}(robinson@cogsci.ucsd.edu), Donald MacLeod¹; ¹Psychology, UC San Diego, ²Cognitive Science, UC San Diego

There is no generally agreed upon formula for expressing saturation and chromatic contrast. Here we investigate saturation coding in early visual cortex by way of the McCollough orientation-contingent color-aftereffect. We have previously shown the McCollough aftereffect strength is linear with induction time, suggesting that the effect is proportional to stimulus effectiveness (Vul, Krizay, & MacLeod, 2008). Is the same true for the saturation of the inducer? Subjects adapted to a fully saturated red and green pair of equal-luminance inducing gratings, produced by a wide gamut LCD. Aftereffect strength was assessed using a nulling technique, and comparing pre- and post-adapt nulls. Halving the inducing saturation of the gratings (by halving the difference in cone excitations) reduced the aftereffect strength only slightly. This suggests a compressive coding of saturation, where equal successive increments in cone contrast produce diminishing returns in the cortical code for saturation. Our result predicts that anomalous trichromats should see a larger McCollough effect. In anomalous trichromats, the apparent difference between red and green is greatly reduced owing to the proximity in peak spectral sensitivity (λ_{max}) between the long-wave and middle-wave cones. During adaptation this only slightly reduces the induced aftereffect, because of the saturation non-linearity we found. In order to null the resulting aftereffect, however, the color-deficiency of the retina must be overcome by adding significantly more chromaticity to the null than a normal viewer would require. Initial evidence supports this prediction; the one anomalous subject tested so far had a McCollough effect several times larger than normal.

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26.302 An ecologically valid description of the light field

Sylvia Pont¹(s.c.pont@tudelft.nl); ¹Perceptual Intelligence lab, Industrial Design Engineering, TUDelft

Situational awareness is composed of several (interrelated) generic frameworks. The luminosity framework is an awareness of the luminous environment or light field. That one indeed perceives the luminous environment is evident from the fact that observers have implicit expectations concerning the appearance of objects as they are introduced into the scene [Koenderink et al., Perception 36, 2007; Pont et al., ECVP, 2010]. Currently, in state of the art computer graphics and in perception research, one often takes recourse to brute force methods to describe luminous environments, e.g. using spherical harmonic approximations (a sort of Fourier analysis of its directional frequency components as represented on a sphere). Although the relationship between these computationally very efficient mathematical components and the constituents of the luminosity framework should certainly be addressed, I propose to investigate the luminosity framework from a different starting point by using a combination of the concepts "flow", "scale", "zones" and "texture" of the luminous environment. Since these concepts were actually formulated to describe the visual appearance of the luminous environment, they seem to be more suitable parameters than the mathematically elegant but perceptually alien spherical harmonics. The "flow" describes the average direction and how it changes through space. The "flow" was defined mathematically as the average flux transport as a function of position in 3D space. In former research we measured it as the set of first order spherical harmonic components and visualized it using light tubes. The "scale" is a term used to describe the diffuseness of the luminous environment. The concept of "zones" refers to regions of different types of luminance, of which one or several may exist in a single scene.

The "texture" concerns a statistical summary of the fine structure of the luminous environment. Applications of this novel description of the light field will be discussed.

26.303 Where we look determines what we see

Matteo Toscani¹(Matteo.Toscani@psychol.uni-giessen.de), Matteo Valsecchi¹, Karl Gegenfurtner¹; ¹Justus-Liebig-University of Gießen, department of Experimental Psychology

It is not yet clear how we form a global impression of the colorimetric properties of real objects. Giesel & Gegenfurtner (2010, Journal of Vision) found that lightness matches were higher than the mean lightness of objects. Here, we investigated whether this effect could be due to observers fixating at the more salient bright parts of the objects. Observers had to adjust the color of a uniform spot of light to the color of one of six objects (three candles, a paper cone, a wool ball and a wool cylinder). Eye movements were measured with an EyeLink II system while the observers performed the task. We replicated the earlier results by Giesel & Gegenfurtner (2010). We also observed that the matched lightness was similar to that of the most frequently fixated object regions, as observers tended to fixate points with above-average lightness. In order to investigate a possible causal link between fixations and color matches, we forced participants to fixate a specific point on the image. This was achieved in a gaze-contingent display by having the image disappear when observers attempted to fixate other points. The matched luminance was higher when observers were forced to fixate in a bright region of the image than when they fixated a dark region. We excluded a possible role of adaptation by forcing observers to match the object color with a test box in a non adapted retinal area. We can thus conclude that the way we perceive the color of objects is driven by the way we look at them, as had been suggested earlier (Kuriki, 2004, Optical Review; Cornelissen & Brenner, 1995, Vision Research). More specifically, objects appear brighter when we look at their brighter side. As a side effect, this leads to more accurate lightness matches that are invariant of object geometry.

26.304 People can reliably detect surfaces that are unlikely to just be reflecting light

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For any given illumination there is a physical limit to the combinations of luminance and chromaticity that can arise by diffuse reflection alone, because reflection can only reduce the intensity of the light at each wavelength. The set of possible combinations is the theoretical object-color set of the illuminant. Naturally occurring surface reflectance is not spectrally unconstrained, so naturally occurring surfaces occupy a fraction of the object-color set. Light that does not arise from diffuse reflection of the illumination, for instance highlights or light from additional sources, can be beyond the theoretical and natural limits. We examined whether observers can detect deviations from these sets. Observers viewed patterns of 120 squares of equal size (sides of about 1 deg). All the colors but one were simulations of surfaces reflecting natural daylight. The spectral reflectances were selected at random for each trial from the surfaces of an urban scene. The simulated illuminant could be either D65 or D50. The color of the target was varied along a line crossing the border of the object color volume. The observer's task was to identify the colored square that was least likely to represent a diffusely reflecting surface under the same illumination as the other surfaces. A staircase procedure was used to estimate thresholds for six different colors for each of the illuminants. Observers could reliably identify the target as soon as it was outside or even close to the border of the natural color-set. This identification was not based on luminance or saturation alone. The ability to detect light that is unlikely to arise from diffuse reflection is probably important for color vision, because light that does not arise from reflectance should be interpreted differently to achieve color constancy.

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26.305 Co-occurrence of luminance and chromatic edges does not always result in suppressed perception of depth from shading

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A sinusoidal luminance grating can be perceived as a surface with a series of depth corrugations. Chromatic information can alter the perceived depth of the corrugations: Kingdom's 'colour-shading effect'. He found that a chromatic sinusoid, orthogonal to a luminance sinusoid, enhances the perceived depth of the luminance-defined corrugation, whilst aligned chromatic sinusoids suppress the depth. One reason put forward for this is that, in the natural world, pure luminance change is likely due to shadow or shading; the co-occurrence of luminance and chromatic change is likely due to reflectance change. In our study, depth perception from shading was explored with a simple combination of chromatic and luminance sinusoids. The stimuli consisted of a luminance and a chromatic sinusoid (each 0.75 cpd), either having the same or orthogonal orientation. Observers were asked to match the amplitude of depth perceived in the luminance corrugation with that of a circular depth pedestal (diameter 2 deg), in a random dot stereogram. As the colour-shading effect predicts, we found for the orthogonal condition, that depth did increase as either chromatic or luminance contrast was increased in the stimuli, although there were large variations in the strength of the effect across our pool of 14 naïve participants. When the chromatic and luminance sinusoids were aligned, some of our observers reported the expected decrease in perceived depth as chromatic contrast was increased. However, around one third of our participants reported instead an increase in the perceived depth. Not all of our participants behave as if the co-occurrence of a luminance and chromatic edge is due to a reflectance change (i.e. a change in the material colour). This challenges the basic logic behind the colour-shading effect. Simpler arguments, based on masking between chromatic and luminance channels could provide an alternative explanation for the perceived depth variation.

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26.306 Do basic colors influence chromatic adaptation?

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Color constancy (the ability to perceive colors relatively stable under different illuminants) is the result of several mechanisms spread across different neural levels and responding to several visual scene cues. It is usually measured by estimating the perceived color of a grey patch under an illuminant change. In this work, we hypothesize whether chromatic adaptation (without a reference white or grey) could be driven by certain colors, specifically those corresponding to the universal color terms proposed by Berlin and Kay (1969). To this end we have developed a new psychophysical paradigm in which subjects adjust the color of a test patch (in CIELab space) to match their memory of the best example of a given color chosen from the universal terms list (grey, red, green, blue, yellow, purple, pink, orange and brown). The test patch is embedded inside a Mondrian image and presented on a calibrated CRT screen inside a dark cabin. All subjects were trained to "recall" their most exemplary colors reliably from memory and asked to always produce the same basic colors when required under several adaptation conditions. These include achromatic and colored Mondrian backgrounds, under a simulated D65 illuminant and several colored illuminants. A set of basic colors were measured for each subject under neutral conditions (achromatic background and D65 illuminant) and used as "reference" for the rest of the experiment. The colors adjusted by the subjects in each adaptation condition were compared to the reference colors under the corresponding illuminant and a "constancy index" was obtained for each of them. Our results show that for some colors the constancy index was better than for grey. The set of best adapted colors in each condition were common to a majority of subjects and were dependent on the chromaticity of the illuminant and the chromatic background considered.

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26.307 Optimizing lighting spectra for naturalness and chromatic diversity

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The naturalness and diversity of colors produced by a light source are important aspects of color rendering which are often difficult to reconcile with conventional illumination. With the advent of modern solid-state light sources almost any lighting spectrum is possible and a new wide range of possibilities for color rendering is available. What spectral profiles optimize these two aspects? We addressed this issue by studying computationally chromatic effects of a variety of light sources with arbitrary spectral distributions. A large number of chromaticity points were chosen around the Planckian locus ranging from 2,000 K - 20,000 K, and for each point a large set of metamers with variable degree of smoothness was generated using the Schmitt's elements method. The general color rendering index (CRI) and the volume of the Munsell set spanned in the CIELAB color space were calculated for each metamer. Consistently with previous findings obtained with smaller samples, the metamers with the maximum CRI at each chromaticity had smooth spectra and the metamers producing the maximum volume of the Munsell set had more structured spectrum. The product of CRI and volume of the Munsell set showed a regular variation in color space and was maximized for chromaticities in the yellow-green region and for spectra medium structured. Similar tendency was obtained with the product of CRI by the number of discernible colors in high-resolution hyperspectral images of 50 natural scenes illuminated by these metamers. In these optimal conditions CRI above 90 could be obtained. The present study shows that it is possible to reconcile chromatic naturalness and chromatic diversity in color rendering by optimizing the spectra and the chromaticities of lighting.

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26.308 The neural basis of lightness and color constancy in the visual system

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In order to extract reliable information about objects in the world from activations on the retina, the visual system must discount variations in the retinal image that occur with changing viewing conditions. Such perceptual constancy operations occur across a range of different stimulus properties. For lightness and color constancy, the challenge is to discount the illuminant and recover the reflectance of a given surface, based only on the light hitting the retina (Palmer, 2000). This means that a difference in lightness or color can be perceived between surfaces that in fact reflect light of the same wavelength, if they are placed in contexts that suggest different illuminations (Adelson, 2000). We presented identical target surfaces within contexts that made them appear different in lightness, as well as reference stimuli that subjects had previously adjusted to match the perceived lightness in each context. An additional experiment was performed using identical target surfaces within contexts that led to a difference in perceived color. We limited our analysis to voxels in visual areas that responded specifically to target surfaces and used multi-voxel pattern analysis (Haxby, 2001) to identify areas where it was possible to distinguish between surfaces with different perceived reflectance, despite identical stimulus wavelengths. This analysis identified areas that carry information about perceived reflectance. We also tested whether correlations between patterns of activation evoked by a target surface and its corresponding reference surface were higher than correlations between patterns evoked by the target and a surface having the same actual luminance/hue. This analysis identified areas that code perceived reflectance rather than properties of light hitting the retina. Because our experience is of inferred reflectance rather than of the wavelengths sampled at the retina, determining the stage in visual processing where these constancy operations occur provides information about the neural correlates of visual experience.

26.309 Dichoptic positive color aftereffect induced by contour figure: a new color aftereffect

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A positive color is perceived when only the contour of the adapting figure was presented to the opposite eye following color adaptation to one eye. We have reported a similar positive aftereffect with van Lier's display (EVP, 2010), but it involves simultaneous adaptation to two complementary colors, and the selection of aftereffects. The present aftereffect is very simple and free from such complicating factors and is quite parallel to the ordinary negative color aftereffect. In this study, we examined the temporal aspect of this new aftereffect to elucidate the site of adaptation. In Exp. 1, we measured the duration of the aftereffect in binocular (same eye) and dichoptic (opposite eyes) conditions. The adaptor was a star shaped figure colored either in red or green against a gray background. Following 1 sec adaptation, the test figure, a black contour of the same shape was presented. The aftereffect lasted for 1.5 sec in average for both conditions. In Exp. 2, we delayed the presentation of the test for 10 to 1000 ms in 7 steps and asked the occurrence and color of aftereffect to see the persistence of the adaptation effect. In the binocular condition, observers perceived negative aftereffect for more than 75% of trials up to 170 ms delay, and the percentage went down to chance level at around 300 ms. The positive aftereffect was almost never perceived. In the dichoptic condition, positive color was perceived in approximately 70% of the trials up to 170 ms, and it went down to chance level at around 300 ms. The negative aftereffect was almost never perceived. These results indicate that the duration of the dichoptic aftereffect is quite short and similar to that of ordinary negative aftereffect, and suggest that the dichoptic adaptation occurs at a relatively low level in the visual system.

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26.310 Filling-in of an Afterimage in Depth Planes

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Van Lier, Vergeer, and Anstis (2009) demonstrated that an outline contour drawn when viewing an afterimage modulated the afterimage percept. When the contours encompassed only part of the region stimulated by an inducer, the afterimage color at that region was strengthened and was seen to spread homogeneously within the contour, even including a region that was not exposed to chromatic stimulation. Here, we investigated variations in the relative depth of the contour and the colored inducing stimulus. As in the previous study, the inducing stimulus was an eight-pointed star with alternating red and green tips and a gray center. The contour consisted of one or two wire-frame lines that formed a four-pointed star. In the one-contour case we observed that the Van Lier afterimage easily transfers across depth planes. Variations in the depth of the wire frame contour did not substantively alter the properties of the afterimage. When two contours were presented simultaneously, but in different depths and with different orientations, the perceived afterimage was stronger (and spread more vigorously to the middle) for the contour perceived to be further away. For the near contour, the tips produce a visible afterimage color but this color did not spread into the interior. The findings demonstrate subtle interactions between boundaries and filling-in mechanisms that depend on relative depth.

26.311 Effects of binocular disparity on color constancy in real 3D scenes revealed with a synopter

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The previous studies have shown that, among many factors that influence color constancy of a scene, the binocular disparity of surfaces in the scene may be an effective one. Most studies have used 3D scenes with binocular disparities produced by two computer-generated stereoscopic images on a display. In this study, however, we used real objects viewed with a synopter to eliminate the binocular disparity of surfaces. This viewing condition allows observers to use a large number of depth cues except binocular disparity for understanding the 3D structure of the scene. In the present experiments the observer's task was to adjust the chromaticity of the test patch located in a real 3D scene so that it appeared as an achromatic sur-

face. The surroundings consisted of painted geometric 3D objects arranged on stairs. An LC projector illuminated the surrounding objects with correlated color temperatures of, 3000K, 6500K and 20000K. We tested three different viewing conditions, (1) binocular viewing condition (with normal disparity), (2) monocular viewing condition (with indefinable disparity), (3) synopter viewing condition (with zero disparity). The results showed that quite good color constancy was obtained in all viewing conditions, and that the binocular viewing condition yielded the best color constancy. These findings indicate that the lack of binocular disparity information reduced the degree of color constancy despite the existence of other depth cues sufficient to understand the 3D structure of the scene. This suggests that the binocular disparity contributes to color constancy by not just providing the object locations or 3D arrangements in a scene.

26.312 The effect of Color-Luminance correlations in surrounding stimuli on color constancy under interocular suppression

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[Purpose] Changes in illuminant color give rise to correlated changes between luminance and chromaticity across various color surfaces in a scene. Such correlations are considered to subserve color constancy (Goltz & MacLeod, 2002). Simple uniform surroundings are also known to a subserve color constancy (e.g. Valberg & Lange-Malecki, 1990). We investigated the effect of color-luminance correlations in the surround on color constancy using interocular-suppression technique. [Method] We measured shifts in color appearance induced by surrounding color stimuli under conditions with and without perceptual suppression for the surround stimuli. We used a chromatic continuous flash-suppression (CFS: Tsuchiya & Koch, 2005) stimulus to evoke consistent interocular suppression for the surrounding stimuli. In the experiment, a test stimulus was presented at the center of the surrounding stimulus in one eye, and the CFS stimuli were presented to the other eye at a refresh rate of 14 Hz. In conditions without suppression, the test and the surrounding stimuli were presented to both eyes. Either Mondrian- or a uniform-surround was used. The Mondrian-surround stimuli simulated the chromaticity of color chips (OSA uniform color scale) under an illuminant with a broad-band spectrum; the illuminant color was green, white (D65), or red. The uniform surround stimuli had the same mean chromaticity and luminance as the Mondrian stimuli. Observers reported whether the test stimulus appeared reddish or greenish. [Results and Discussion] In the Mondrian condition, color shifts with the CFS were smaller than those without it. In contrast, in the uniform-surround condition, the color shifts were approximately the same between the two suppression conditions. These results may suggest that color shifts induced by color-luminance correlation among surrounding colors at higher stages in visual processing than the stage that integrates binocular information.

26.313 Visual perception of material affordances

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Material perception may be as important as object perception for successful interactions with the environment. Possibly the most important facet of visual material identification is to infer properties from the available information that can provide predictions for the appearance of the material in other states, for effects of the material on other sensory modalities, for the calibration of motor actions, and most importantly for potential uses, i.e. affordances. We present an investigation of the inference of useful properties of fabrics from exclusively visual information. We used 261 color images of flat fabrics, presented on a monitor as similar sized squares surrounded by black. We asked observers to rate each image separately on four property dimensions anchored by the poles: soft - rough, stiff - flexible, warm - cool, and water-repellent - water-absorbent. To guide observers in inferring each property, we presented them with a question aimed at potential uses of the material. For data analysis, we used images that were rated consistently across repetitions and observers. We show that between 30% and 50% of the images rated by the observers as belonging to one property class were assigned consistently across observers. Based on verbal descriptions from the sources where we obtained the images, it seems that visual judgments of affordances are close to the ground truth, but to make more definite statements we will run physical and tactile tests on fabrics. Attempts at modeling fabrics have shown that since stitches/knits can be

resolved visually, the surface cannot be assumed to be flat, so 2-D image-statistics and texture-mapping schemes are insufficient. As an alternative, we are using results that affordance groups like soft, flexible, and water-absorbent, and rough, stiff, and water-repellent, contain a large proportion of common images, to identify the critical perceptual qualities that underlie inferences of multiple material qualities.

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26.314 Near-optimal tuning of trichromatic vision for constant surface identification in natural scenes

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There have been several partial attempts to explain the number and spectral locations of the cone photoreceptor pigments of the normal human eye; e.g. that specifically the medium- and long-wave pigments of trichromatic primates are optimal for discriminating fresh leaves from mature foliage. The aim of this study was to test a more general hypothesis, namely, that long-, medium-, and short-wave pigments are optimal for identifying objects within the natural world despite changes in the color of the illumination. To determine the theoretical limits on identification performance, computer simulations were performed in which the number of cones, pigment spectral locations (on a log-wavelength axis), and post-receptoral interactions were allowed to vary. Stimuli were generated from high-resolution hyperspectral images of 50 close-up and distant images of natural scenes. Of these scenes, 29 were classed as predominantly vegetated and 21 predominantly nonvegetated. From each scene, 1000 points were chosen randomly and the cone signals at each point were calculated for two illuminants selected randomly from combinations of direct sunlight and blue skylight and these same lights filtered by a leafy canopy. Allowance was made for absorption in the ocular media. The information retrieved, derived from an estimated probability mass function for identification performance, was calculated for one, two, three, and four cone pigments. The average information retrieved increased with increasing pigment number, but it approached an asymptote with three pigments. Optimal spectral locations differed according to whether the scenes were predominantly vegetated or nonvegetated, but, for both types, spectral locations were generally shifted towards longer wavelengths with respect to their normal positions, although little additional information was gained by the shift. The number and tuning of normal cone pigments seem to be nearly optimal for surface identification in the natural world.

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26.315 A model of induced visual fading of complex images

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Simons et al. (2006, JoV) described a visual fading effect where a low-pass filtered complex scene faded to a uniform luminance and hue when viewed with steady fixation. The extent and speed of fading was enhanced when transient dots were superimposed on the image. New simulations of Grossberg's FACADE model of visual perception demonstrate that the model is able to account for many of the properties of this kind of visual fading. In the model visual percepts are defined by filled-in colors that are trapped by appropriate boundary signals. In complex scenes these boundary signals form boundary web groupings that block colors from spreading and interacting. With low-passed images and steady fixation local adaptation of orientation-sensitive cells that generate boundaries gradually weaken thereby freeing colors to spread and fade. The same kind of orientation-based adaptation produces an orientation after-response at the offset of transient dots. These orientation after-responses are orthogonal to the boundaries that surround the circles, and as result they interfere with boundary grouping mechanisms for other parts of the scene. By weakening the boundary web groupings, this interference accelerates color spreading and perceived fading. Global decreases in contrast can cause a similar type of orientation after-response for contours across the scene and also accelerate perceived fading. Overall, the model simulations match many of the empirical findings.

26.316 Red/Green Color Naming Declines in the Periphery. "Blue"/"Yellow" Does Not. What Happens in Visual Search?

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The ability to name red and green declines earlier in the periphery than the ability to name blue and yellow (Hansen, Pracejus, & Gegenfurtner, 2009; Newton & Eskew, 2003). This is thought to be due to differences in retinal wiring. In the fovea, midretinal ganglion cells receive a single L or M cone input to their central receptive fields and multiple, random, cone input to the surround, yielding chromatic opponency. In the periphery, however, midretinal cells receive multiple cone central input, reducing chromatic opponency (Gunther & Dobkins, 2002; Mullen & Kingdom, 1996, 2002), and apparently also reducing subjects' ability to name red and green stimuli. The ability to name blue and yellow (unique blue and yellow or retinal/physiological violet and chartreuse), however, remains farther into the periphery. These colors are processed by the small bistratified cells, which receive S vs. L+M cone input throughout their entire receptive fields, without center/surround organization, across the entire retina. Thus, "blue"/"yellow" performance would not be predicted to vary with eccentricity. Here we test the effect of this red/green peripheral drop-off in a visual search task. We first mapped out color naming performance, and found that red/green performance declines sharply beginning around 40° eccentricity, whereas violet/chartreuse performance declines less sharply around 45-50°. In a feature visual search task (e.g., red target dot amongst green distractor dots; twelve, 2.5° diameter dots; 0, 20, and 45° eccentricity; 12 subjects), these differences in retinal wiring significantly impaired red/green visual search more than violet/chartreuse visual search at 45°.

26.317 Detecting animals in natural surroundings: The role of color distributions.

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Coloration and pattern are thought to play roles in crypsis for evading predators, and display for attracting mates or warning enemies. Colors of animals and their natural surroundings form distributions elongated between spectral reflectances and illumination spectra. We investigate whether color distributions contribute to camouflage and display independent of spatial information. We obtained 30 images of animals distinctly visible on the natural surround, and 29 images of animals camouflaged against their background. Colors were extracted from each pixel in the animal's image, and each pixel in the surrounding annulus of roughly the same width as the animal. The surround colors were randomly placed in the pixels of an 8 deg square, and the animal colors randomly in a 1.5x6 deg rectangle. Random masks were made as averages of all the images. Duration thresholds for discrimination of each animal color distribution from its background distribution, were measured by presenting rectangles randomly as horizontal or vertical in the center of the square, followed by a mask, in a 2AFC method of constant stimuli for durations from 8.5 to 100 msec. Besides the original distributions, the experiment also used isoluminant and achromatic versions of the random displays. Thresholds were determined from psychometric curves fitted to each image for each condition and for each observer. Comparing isoluminant thresholds to thresholds for the original distributions, reveals whether an animal distribution can be reliably detected on the basis of chromatic information alone. Comparing achromatic thresholds to thresholds for the original distributions reveals whether the addition of chromatic information enhances detection of an animal distribution. In general, both tests separated the images into the same groups, animals that could be detected using chromatic signals, and animals that could not. We will show that the usefulness of chromatic signals is related to the angular difference between color distributions.

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26.318 Hue perception under scotopic light levels

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The color appearance of an object under scotopic luminance conditions varies depending on the context in which the object is viewed, irrespective of the photopically assigned color. Specifically, an object will appear bluish-green when viewed in isolation, but may appear red or orange

when accompanied by a separate object with a higher scotopic luminance (Pokorny et al., 2006). Previous studies on relational scotopic color used free viewing in space and time and very large samples. We investigated the spatial and temporal stimulus conditions required to illicit relational hue percepts under scotopic conditions. A 1 deg test ring was viewed at a 7 deg retinal eccentricity on a CRT covered by neutral density filters. The test luminance was approximately $-4 \log$ photopic cd/m². The test ring was surrounded by either 2 (simple context) or 4 (complex context) 1 deg inducing rings, split evenly on each side of the test ring. For a total of 120 (x 10 repeats) trials, the stimulus duration (5 temporal presentations), inducer spacing (3 conditions), and inducer contrast (4 conditions, from -80 to +80% contrast) were varied for both simple and complex context. A hue scaling technique was used to measure perceived hue and saturation. In the absence of inducers, observers did report hue percepts, although perceived saturation was low (5-15%). In the presence of inducers, the test appearance shifted between reddish-yellows to bluish-greens with a change in inducer(s) contrast polarity, and more reddish hues were perceived with a decrease in inducer spacing. Hue percepts were consistent across stimulus durations, and overall, less red content was reported with complex context. Spread light alone is not sufficient to account for hue shifts, suggesting higher-order color mechanisms play a role in hues percepts at scotopic light levels.

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26.319 Hyperspectral one-dimensional visual stimulator and its application of metameric test.

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A system with the hyperspectral camera and display can reproduce spectral information of objects. With this technology, a gamut of the system covers a full color range, and it is possible to avoid observer metameric failure. In this presentation, we propose a new method to examine the metameric failure of each individual. In this study, we modified a programmable light source to build a new type of visual stimulus generator. The spectral components of the light and its position were arbitrarily set by controlling the liquid crystal panel. Seven-hundred-and-sixty-eight lines could compose independent combinations of the monochromatic light, whose wavelengths were selected by switching the horizontal direction of 1024 pixels in the panel. Our stimulus had seven regions (one region had about 110 lines), four of which were used to present equivalent energy white (EEW), and three were used to present three different combinations of RGB whites. Each RGB white was surrounded by two EEWs. The combinations of RGB were: (450, 560, 600 nm), (470, 560, 600 nm), and (450, 570, 600 nm). The subjects were asked to answer the order of the three RGBs that resembled EEW. At the same time, the subjects answered the magnitude of the difference between each RGB white and EEW. Seven color normal subjects (ages: 26 to 53) participated in the preliminary experiment. Although we did not obtain clear trends in the order of resemblance, a noticeable difference in the responses was observed in RGB1. The younger subjects called the color green, while the older called it yellow or red. We speculate that the short wavelength components in RGB1 were absorbed by older crystalline lenses. This simple test shows a potential of our system as a useful tool for detecting absorption of the crystalline lens in the clinic.

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26.320 Scotopic sensitivity regulation: noise or gain ?

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Thresholds for 200 ms test spots in rod isolation conditions were obtained after dark adaptation was complete ('absolute thresholds'), on dim fields ('increment thresholds'), and 200 to 600 ms after the field was turned off ('extinction' thresholds). Fields were steady or flashed. Field intensity was below 3 scotopic td to avoid rod light adaptation. For tiny (5' arc) spots, increment thresholds followed the square-root (Rose- DeVries) law, and extinction thresholds fell to the absolute threshold. For large (1.3 deg) spots, increment thresholds followed Weber's law, while extinction thresholds followed the square-root law after turning off steady fields but remained at absolute threshold after the fields were flashed. These results can be

explained by a combination of dark light, photon-driven noise (which is eliminated when the field is turned off), and light adaptation of the neural elements mediating detection of the large (but not the tiny) spot.

Multisensory processing: Visual, tactile and vestibular interactions

Saturday, May 7, 2:45 - 6:30 pm

Royal Palm 6-8, Poster Boards 321 - 333

26.321 A multisensory visuotactile illusion induced by monocular occlusion with a black contact lens does not depend on touch signals on the face: evidence from behavioural and modelling studies.

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Neural integration of different sensory modalities provides a meaningful, unified representation of the world. However, conflict between modalities can cause illusory perceptions when inputs are sufficiently incongruent. As shown previously (Wolfe & Carpinella, 2008, ECVF), monocular blindness induced by an occluder contact lens in the absence of congruent tactile input causes ipsilateral facial paresthesias and, in some cases, neglect-like symptoms. The strength and extent of the effect is stronger when the dominant (rather than non-dominant) eye is occluded. More recent work (Jobst et al., 2010, SfN) shows that, furthermore, everyday experience modulates the strength of the effect as non-contact wearers have larger facial areas of paresthesias than contact wearers. The paresthesias are experienced without any corresponding elevation of tactile detection threshold as tested with an aesthesiometer (Di Noto & DeSouza, 2010, SfN). Consistent with findings by Wolfe and colleagues (2007, P&P), in all studies, paresthesias were found mainly ipsilateral to the occlusion and were accompanied by an illusory ipsilateral eyelid droop. We developed a computational model of this illusion that has inputs from both eyes and a somatosensory signal from the face. We trained the network to make gaze shifts to visual and somatosensory targets. After the network was trained, we removed the input from one eye to model the effect of an occluder lens. We discovered that the network could still make gaze shifts, but that the signals from the hidden and output layer units to the space ipsilateral to the occlusion were not as efficient as signals to the contralateral space. Underlying mechanisms may include top-down signaling from bimodal visuo-tactile brain regions to somatosensory areas and/or bottom-up signaling from superior colliculus and related structures. Our results demonstrate that congruent inputs from visual, somatosensory, and proprioceptive modalities are necessary for the unified interpretation and efficient navigation of peripersonal space.

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26.322 Different tactile stimuli produce different activation patterns in occipitotemporal cortex

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Activity in visual cortex with tactile perception has been observed in people with normal or impaired vision. The functional significance of this activity is unclear. In this fMRI study, we ask whether different tactile stimuli produce distinguishable multi-voxel activation patterns in occipitotemporal cortex, and whether these patterns differ for normally sighted and visually impaired subjects. In separate block-designed scans, three types of tactile stimuli were presented to contrast shapes ("X" vs. "O"), spatial configuration (two dots placed in quadrants 1,3 vs. 2, 4 defined by a "plus"), and orientation (horizontal vs. vertical bars). Subjects performed tactile shape, distance, and orientation tasks for these three types of stimuli with their eyes closed. Preliminary data from four normally sighted subjects and one low vision subject revealed activation in somatosensory and motor cortex and multiple regions of visual cortex, including primary visual cortex, lateral occipital cortex (LOC) and inferior temporal cortex (IT). Seven regions of cortex were selected as regions of interest (ROIs): foveal representation near the occipital pole, LOC, IT from each hemisphere and the left somatosensory cortex representing the right index finger. Spatial patterns of voxel activity were extracted for each type of stimulus from these ROIs. Correlations were computed between these patterns from the same stimulus

category (e.g. X-X) versus different stimulus categories (e.g. X-O). In the LOC and IT, there is evidence of higher within-category correlations than across-category correlations in the shape discrimination experiment, consistent with their multimodal function in processing shapes. In the fovea ROI, the correlations were higher in the spatial configuration experiment than in the shape experiment (0.44 vs. 0.26), perhaps indicating that retinotopic cortex is more involved with tactile configuration than shape. The correlation analysis did not reveal a definitive difference between our low vision subject and the normally sighted subjects.

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26.323 Recognition of Tactile Pictures is Compromised by Global Shape Acquisition

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Numerous studies have demonstrated that sighted and blind individuals find it difficult to recognize two-dimensional tactile pictures of common objects. However, it is still not clear what makes recognition of tactile pictures so difficult. One possibility is that observers have difficulty acquiring global shape from haptic information when feeling the images. Alternatively, observers may have an accurate understanding of the shape but are unable to link it to a particular object representation. We conducted two experiments to determine where tactile picture recognition goes awry. In Experiment 1, we tested blindfolded sighted observers on their ability to recognize an array of tactile pictures. We then correlated recognition with image characteristics that influence shape perception and object naming. We found that recognition of tactile pictures correlated with image characteristics that affect shape acquisition (symmetry and complexity). In Experiment 2, we asked sighted drawing experts to draw their perception of the tactile pictures after feeling them. The drawing experts produced three types of drawings when they could not recognize the tactile pictures: 1) drawings that do not look like objects, 2) drawings that look like incorrect objects, and 3) drawings that look like the correct objects. The majority of errors reflected an inaccurate perception of the global shape of the image (error type 1). Our results suggest that recognition of simplistic tactile pictures of objects is primarily inhibited by low-level tactile shape processing rather than high-level object recognition mechanisms. Furthermore, instances of recognition failure even with accurate shape acquisition indicate that tactile information might be stored as chains of simple local features without the synthesis of a global gestalt.

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26.324 Direct and indirect haptic calibration of visual size judgments in adults and children

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It has long been suspected that touch plays a fundamental role in the calibration of visual perception, and much recent evidence supports this idea (e.g. Gori et. al. 2008, Gori et.al. 2010). However, as the range of haptic exploration is limited by the kinematics of the body, the contribution of haptic signals to the calibration process should occur only within the reachable region of the haptic workspace (peripersonal space). To test this hypothesis we measured visual size perception and showed that it is indeed more accurate inside the peripersonal space. We then show that allowing subjects to touch the (unseen) stimulus after observation restores accurate size perception. The accuracy persists for some time, demonstrating that the system has become recalibrated. Finally, we show that observing an actor grasp the object also produces accurate and lasting size perception, suggesting that the calibration can also occur indirectly by observing goal-directed actions, implicating the involvement of the "mirror system". We are currently measuring calibration of visual bias in children aged 6 to 14 years, and the results will be reported at the conference.

26.325 Curvature aftereffect and visual-haptic interactions in simulated environments

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Repeated haptic exploration of a surface with curvature results in an adaptation effect, such that flat surfaces feel curved in the opposite direction of the explored surface. Previous studies used real objects and involved contact of skin on surface with no visual feedback. To what extent do cutaneous, proprioceptive, and visual cues play a role in the neural representation of surface curvature? The current study used a Personal Haptic Interface Mechanism (PHANToM) force-feedback device to simulate physical objects that subjects could explore with a stylus. If haptic aftereffect is observed in exploration of virtual surfaces, it suggests neural representations of curvature based solely on proprioceptive input. If visual input plays a role in the absence of haptic convexity/concavity, it would provide evidence for a visual input to the neural haptic representation. Method. Baseline curvature discrimination was obtained from subjects who explored a virtual surface with the stylus and reported whether it was concave or convex. In Experiment 1, subjects adapted to a concave or convex curvature (± 3.2 m-1) and reported the curvature of a test surface (ranging from -1.6 m-1 to 1.6 m-1). In Experiment 2, subjects adapted with their left hands and tested with their right (intermanually). In Experiment 3, subjects were given visual feedback on a computer screen that the trajectory of the stylus tip was a curved surface, while the haptic surface was flat. Results. In Experiment 1, subjects showed a strong curvature aftereffect, indicating that proprioceptive input alone is sufficient. Subjects in Experiment 2 showed weaker but significant adaptation, indicating a robust neural representation across hands. No aftereffect was found with solely visual curvature input in Experiment 3, suggesting that the neural representation is not affected by synchronized visual feedback, at least when two modalities do not agree. Implications for visual-haptic representations will be discussed.

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26.326 Optimal visual and proprioceptive cue integration in motion perception

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When we move our hands, both visual and proprioceptive input provides information about the motion. We show that subjects integrate these two modalities in a Bayesian optimal way in a two-part study. In the first part, we measured the reliabilities of subjects' estimates of movement direction using only proprioceptive or only visual motion information. In the proprioceptive condition, a robot arm moved a manipulandum held by subjects 15 cm back and forth along linear trajectories sampled uniformly from -25 to -35 and 55 to 65 degrees relative to the midsagittal plane. Subjects judged whether the motion direction presented in a second interval was clockwise to that of the first interval. In the visual condition, subjects made similar judgments of spatial-temporally correlated noise patterns moving with the same velocity profiles as the robot in the proprioceptive condition. We modulated the reliability of the visual information by using two different signal-to-noise ratios in the visual stimuli. In the second part, the robot moved subjects' hands behind a mirror while they viewed similar visual patterns (spatially co-aligned with the manipulandum held by subjects). The visual motion either equaled that of the robot or deviated in direction by +/-10 degrees. Subjects adjusted a dial to indicate their perceived motion direction. Subjects finished two sessions of counter-balanced proprioceptive and visual discrimination trials and two sessions of the visual-proprioreceptive adjustment task. The reliability of each modality was computed from fitted psychometric functions from proprioceptive and vision-only discrimination sessions. Relative cue weights were estimated by regressing subjects' direction judgments in the last two sessions against the directions suggested by each cue. Subjects gave slightly more weight to vision in the high visual SNR condition but relied less on the visual cue in the low SNR condition as predicted by the threshold data.

26.327 Visual smooth pursuit of proprioceptive signals is enhanced by task-irrelevant dynamic noise

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Smooth pursuit eye movements (SPEM) are an important mechanism for tracking behaviorally relevant objects as they move through the environment. Despite their obvious importance in tracking visual objects, studies have shown that it is possible to visually track stimuli in other modalities, albeit with greatly reduced gain (Berryhill, 2006). For example, SPEM is possible to a limited extent when tracking one's own hand in complete darkness, suggesting that proprioceptive information is available to the SPEM system. However, tracking of proprioceptive position is abolished if a stationary visual surface is presented between the observer and his/her hand (Watanabe & Shimojo, 1997), indicating that conflicting visual information either eliminates or effectively vetoes proprioceptive signals. Nevertheless, it may be possible for certain types of visual information to actually enhance these signals.

Here, we demonstrate that presentation of a dynamic random noise stimulus facilitates smooth pursuit of proprioceptive signals. Participants (n=8) were asked to visually track their hand as they moved a slider along a one-dimensional track. There were four conditions: Hand Visible (dimly lit room), Hand Invisible (total darkness), Static Noise and Dynamic Noise. In the noise conditions, subjects moved their hands behind a mirror that displayed either dynamic or stationary white noise.

Replicating previous results, participants showed a limited ability to visually track proprioceptive signals alone (Hand Invisible), and this ability was eliminated by the presentation of static noise. Importantly, presenting dynamic visual noise markedly improved participants' ability to smoothly track their hand movements, resulting in a larger proportion of trials containing SPEM, higher gain in the pursuit signals, and fewer catch-up saccades during the dynamic noise condition.

Evidently, task-irrelevant motion information can improve visual smooth pursuit of proprioceptive signals. The addition of visual motion noise functionally un masks the influence of proprioceptive inputs to the smooth pursuit system.

26.328 The psychophysics of phantom sensations evoked by Ramachandran's mirror: temporal dynamics and individual differences explored using the phantom pulse effect in normal (non-amputee) observers.

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Ramachandran, Altschuler and others have shown, in well-known studies, that viewing a mirror reflection of one's moving intact limb can reduce phantom limb pain in single-limb amputees, and can evoke phantom sensations in non-amputee normals. Peterzell and colleagues have found that these effects can be amplified in some observers by using stroboscopic self-motion ("the phantom pulse") (VSS 2006, 2007, 2010). In these studies, Ramachandran's simple mirror is modified by using a real-time video image of the observer that flickers between a normal mirror image and a mirror reversed image. When normal observers view themselves and their movements in this way, they sometimes report tingling, numbness, tickling, pressure, heat, cold, or involuntary movement in their invisible, non-moving limb. In the present study, the temporal tuning of the phantom pulse effect was studied (in 8 normal observers, who previously reported experiencing the phantom pulse) by measuring the estimated magnitude of phantom sensations at 0, 0.5, 1, 2, 4, 8 and 12 Hz. In all observers, optimum perceptual effects were found to occur at 0 to 2 Hz. Only two individuals experienced peaks at 0 Hz (no temporal modulation, akin to Ramachandran's simple mirror). Four individuals peaked at 1 Hz, with the remaining two peaking at 2 Hz. At 4 and 8 Hz, all subjects reported zero or near-zero magnitudes. However, all subjects reported above zero magnitudes at 12 Hz. We speculate that neurons with similar transient temporal properties contribute to these profound perceptual effects. The present results imply that that the neural mechanisms underlying Ramachandran's mirror-based interventions for phantom limb pain are temporally tuned. Future use of a temporally-modulated stimulus may enable researchers to examine physiological correlates of these effects using EEG and fMRI.

26.329 A New Method To Induce Phantom Limbs

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We present a simple method using a dark room and a camera flash to induce three novel "out of body" effects. If one is dark adapted, a brief, bright flash may bleach the photoreceptors, allowing whatever is seen during the flash to be "imprinted" on the retinas for several seconds. 1) To induce a feeling of weightlessness, seated subjects looked at their legs during the flash and, after the positive afterimage had formed, directed their eyes to the ceiling. The afterimage of their legs was then projected onto the ceiling, inducing a feeling of weightlessness. 2) To induce a feeling of "phantom" limbs, seated subjects, with feet on the ground, were instructed to look at their thighs and the ground in front of them during the flash. After the positive afterimage had formed, subjects straightened their legs. This uncoupled the visual feedback (seeing a static image of the ground in front of them) from the proprioceptive feedback (feeling their legs move in front of them). Subjects reported that their legs felt lighter than normal and like ghost or "phantom" legs. (Patients with phantom limbs experience similar discrepancies between visual feedback and where they feel their phantoms moving.) Some subjects even reported a loss of ownership of their legs, stating that they felt like they no longer had legs! 3) If the converse is tried (subjects extend their legs, look at their extended legs during the flash and, after the positive afterimage has formed, bend their legs, a feeling of paralysis was reported. The visual image of "legs straight" remained unchanged while the proprioceptive movement suggested otherwise. These effects may have relevance to chronic pain and fibromyalgia, as out of body experiences may allow chronic pain sufferers to feel "outside" of their pain.

26.330 Self-produced stimulation can elicit rubber hand illusion

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The rubber hand illusion (RHI) is a phenomenon in which hidden human touches to a hand are perceived as arising from a fake hand. The RHI is known to reflect the role of multisensory interaction in coherent body representation. While RHI has mainly been studied using tactile stimuli provided by an experimenter, sensory consequences from self-produced stimulation have been shown to elicit percepts that differ from those given by identical, but externally produced, stimulation. Here we investigated whether an externally-produced stimulus is essential for eliciting the RHI. To address this issue, a 3D haptic device was used. This device allows participants to touch their own real, but hidden, hand while simultaneously viewing a virtual fake hand. Two conditions involved self-produced-touch and externally-produced-touch. In the self-produced-touch condition, participants moved their right hand with the haptic device to repeatedly touch their invisible real left hand. In this condition, a virtual left hand was visible and the pointer of the haptic device touched this hand in perfect synchrony with a participant's right hand motions. In the externally-produced-touch condition, an experimenter repeatedly touches a participant's real hidden (left) hand, again using the haptic device. Results indicated that RHI emerged in both conditions. Participants' reports of proprioceptive drifts from real hand position showed RHI in the self-produced-touch condition although amplitudes of the drifts were smaller than in the externally-produced-touch condition. Average ratings on the RHI questionnaire provided converging data. These findings lead to the conclusions that self-produced stimulation can elicit an RHI illusion that conveys a feeling of ownership of a visible fake hand, and externally-produced tactile stimulation appears unnecessary for RHI. Causes of reduced RHI with self-produced tactile stimulation are discussed.

26.332 Perceived direction of self-motion from upward/downward vestibular and orthogonally directed visual stimulation

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Previously, we reported a crossmodal integration in perceiving directions of self-motion from orthogonally directed visual and vestibular information. When observers were seated upright and experienced real leftward/rightward or forward/backward body motion while viewing translating optic flow consistent with visual upward/downward or leftward/rightward

motion; or expanding/contracting optic flow consistent with forward/backward self-motion, they perceived distorted self-motion directions intermediate to those specified by visual and vestibular information (Sakurai et al., 2010, VSS). Here we report data for conditions in which observers lay supinely on an oscillating motor-driven parallel swing providing real upward/downward motion in body coordinates but discrepant to gravity coordinates, while viewing orthogonal optic flow patterns, phase-locked to the swing motion. Optic flow patterns consisted of leftward/rightward oscillatory translational optic flow (vertical sine wave gratings) or expanding/contracting oscillatory optic flow (concentric gratings). Observers were cued with a sound to indicate their perceived direction of self-motion during one half of the swing period, and reported their perceived direction of self-motion for each combination of visual and vestibular information by performing a rod-pointing task. When upward/downward body motion was combined with visual leftward/rightward optic flow, observers' direction judgments progressively favored the direction specified by vision with increasing amplitude of optic flow, as in our previous reports, suggesting a weighted combination of visual and vestibular cues in this context. When real upward/downward motion was combined with visual expanding/contracting optic flow, some observers' judgments were vision-only or vestibular-only, suggesting that multimodal integration in this context is an either-or process rather than a weighted combination of both inputs for these observers. Being compared to our previous reports, one possible reason for this weighted combination failure is the discrepancy between body coordinates and gravity coordinates.

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26.333 A Model for the Enhancement and Multi-Modal Integration of Multi-Spectral Information in Rattlesnake

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We applied oscillatory sensory binding theory to the enhancement and integration of multi-spectral information. Coupled neural oscillators are often used to understand visual binding problems, but have barely been applied to other kinds of sensory integration. Under some conditions, oscillatory coupling of neurons can result in synchronized enhancement of the coupled neural responses. A similar enhancement or amplification has been seen in a variety of multispectral and multisensory systems (including those of humans), motivating our use of coupled oscillator models. Here we applied Hugh Wilson's (J. Theo. Biol., 1999) model of excitatory-coupled Class I neurons (which can fire at very low spike rates) to the integration of infrared and visible responses in pit vipers. In addition to its eyes, the rattlesnake has facial pits (rich in heat-gated ion channels) which transduce infrared information. In rattlesnake optic tectum there are neurons that respond only to infrared or only to visual stimulation in isolation, but which respond with increased firing rates when both stimuli are present. We model these cells (from Newman & Hartline, Science, 1981) as members of a coupled neural oscillator network; they are each driven by one kind of sensory information, but when both are active, their spike trains synchronize at a firing rate higher than either alone. If both coupled neurons feed their spike trains into a third common neuron, this cell can behave like rattlesnake "enhanced OR" cells, which respond to either stimulus but with an enhanced rate when both are present. Similarly, an inhibitory-coupled neural oscillator network models related classes of rattlesnake neurons that exhibit sub-additivity. Since both enhanced single modality and "enhanced OR"-like units are found in superior colliculus of many animals, for many pairs of sensory modalities, this model may be generally applicable to multisensory integration.

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Perceptual organization: Contours and surfaces

Saturday, May 7, 2:45 - 6:30 pm

Orchid Ballroom, Poster Boards 401 - 419

26.401 Functional organizations underlying illusory and kinetic contour processing in early visual cortices V1 and V2 of macaques

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The abutting line illusion and motion defined boundary are among the most frequently used second-order patterns in visual neuroscience and psychological studies. However, the processing of illusory and kinetic contours has been surprisingly difficult to localize within the visual pathway. With our home made in vivo dual Optical Imaging rig, the functional organizations of V1 and V2 in 4 macaques have been systematically charted for abutting line illusory contour (IC) and white-noise defined kinetic grating (KG) stimuli. We have observed clear modular assemblies of cells in V1 and V2 responded to IC and KC stimuli. By closely examination of the spatial alignments of these orientation domains activated by moving luminance sinusoidal gratings (sLG), IC and KG through pixel by pixel comparison, we found that the orientation domains in V1 and V2 activated by IC stimuli were only partly in register with those activated by real contours of drifting luminance gratings of the same orientation. In contrast, the movement of white-noise kinetic gratings (KG) produced orthogonal orientation domains instead that were actually elicited by first-order local motion within KG stimuli. By directly comparison with real contour stimulus of sinusoidal gratings, the signal strengths were relatively much weaker for both IC and KG responses in V1 and V2, as expected. Our observations revealed that the functional organization and cortical mechanism in V1 and V2 for processing IC is fundamentally different from those of KG, which involve direction selective neuron populations from segregated processing channels. Thus these data indicate that the motion defined boundary is most likely processed in the dorsal pathway while the illusory contour is processed in the hierarchical stages above V1 and V2 in the ventral stream of macaque. Correspondence: w.wang@ion.ac.cn

26.402 Contour complexity and contour detectability

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Previous work on contour integration has shown that contours with higher curvature are less detectable than those with lower curvature (Field, 1987; Geisler et al., 2001). Contour curvature has also been related to information content, with points of high curvature postulated to carry the most information (Attneave, 1954). This idea was formalized in Feldman and Singh (2005), who expressed the information content, or surprisal, of a contour point as a function of the local turning angle. As a measure of contour complexity, we propose that contour surprisal can be integrated along the length of a contour, yielding a principled measure of cumulative contour complexity. We conducted a series of contour detection experiments to test how the complexity of a contour relates to its detectability. Subjects were shown contours embedded in random monochromatic pixel noise. In a 2IFC task, subjects indicated whether the contour was present in the first or second stimulus. In the first experiment, two contour lengths were tested, with 5 levels of surprisal each. We found a substantial decrease in detectability with increasing contour complexity; while simple (i.e. relatively straight) contours were readily detected, detection of complex (i.e., unpredictably undulating) contours approached chance levels. In a followup experiment, we investigated how the distribution of curvature along the length of the contour influenced detectability; here the results showed independent influences of both local curvature and global contour form. Our approach to contour complexity goes beyond conventional accounts based on simple curvature, because the underlying probabilistic formulation allows global factors to be readily incorporated into the measure. This in turn allows complexity to be quantified in a broader class of contours than is possible in conventional (local) accounts, for example in closed shapes.

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26.403 Interpretation of surfaces as revealed by object motion behind occluders

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A moving object is temporarily invisible as it passes behind an occluding surface, but people perceive it as moving continuously behind the occluder, suggesting that the representation of the moving object is amodally maintained during its disappearance. In this study, we investigated whether amodal representation of a moving object can persist when relative surface depths do not favor occlusion, in a situation where an occluding surface has an aperture in it. We manipulated the binocular disparity depth of the surface seen through the aperture in 3D displays, ranging from the depth of the occluder to that of background. In Experiment 1, subjects viewed apparent motion displays of two alternately presented tokens abutting each side of an occluder, and indicated in a yes/no task whether they saw the motion tokens passing behind the surface within the aperture. In Experiment 2, subjects viewed continuous motion displays of a moving object which was invisible as it passed behind an occluder, and indicated whether they saw one object or two. When the surface in the aperture was close in depth to the background, observers were less likely to perceive the motion occluded by this surface, but reported two distinct object motions separated by the aperture. But given sufficient depth difference between the surface in the aperture and the background, they reported occlusion of a moving object by this surface, even though the object was slightly in front of it (so that occlusion of the whole path was geometrically impossible). These findings suggest that the motion signal produced by dynamic occlusion is strong enough that even when surface depths do not support occlusion of an object, the impression of a continuously moving object does not cease, but its amodal representation persists so that the object's disappearance is attributed to occlusion by a more distant surface.

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26.404 Spatiotemporal Contour Interpolation in Four Dimensions

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Purpose. The visual system shows impressive capabilities to form complete objects from fragments presented across gaps in both space and time. Research has revealed the importance of particular spatial and temporal relations, known as spatiotemporal reliability (STR) in dynamically occluded and illusory two-dimensional objects (Palmer et al. 2006). Other work has shown that related geometric constraints (3D reliability) predict interpolation in 3D static displays (e.g. Kellman et al. 2005). No previous work, however, has examined the ecologically important case of interpolation in moving 3D displays. We used an objective performance paradigm to test an extended theory of STR with moving illusory 3D objects. Methods. In Experiment 1, subjects viewed a 3D movie with an illusory shape, parts of which were defined by sequential, partial occlusion of narrow rectangles. The displays required spatiotemporal interpolation because pairs of inducing edges never appeared in any static frame. Object contours were reliable on half of the trials. Reliability was disrupted by shifting one fragment either laterally (2D disruption) or in depth (3D disruption). Experiment 2 was a monocular version of Experiment 1. Because conditions leading to unit formation have been shown previously to produce performance advantages in a shape discrimination paradigm, we expected greater sensitivity for the reliable conditions compared to the non-reliable ones. Results. There were two main effects. First, subjects showed greater sensitivity for differences in spatial configurations that were reliable than those that were not. Second, 2D disruptions of reliability had a greater effect on sensitivity than 3D disruptions. Conclusions. 3D misalignment in dynamic displays showed weaker effects on interpolation than in 3D static interpolation, possibly due to difficulty in extracting accurate depth information from moving, sequentially exposed object fragments. Under these conditions, 2D spatial reliability appears to be the major determinant of spatiotemporal object formation.

26.405 Achromatic surface color depends on filling in shape

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Purpose. Previous research has shown that the perception of interpolated shape depends on the filling in of achromatic surface color. Here, we examine the opposite relation—whether interpolating shape modulates the lightness of nearby surfaces. Method. Twenty observers discriminated fat and thin rectangles, the tops and bottoms of which were connected by illusory contours. Inducers were either all black (to produce a lightened illusory surface) or all white (to produce a darkened surface). In all trials, a small target briefly appeared at the same location—either just within the surface of a fat shape or just outside the surface of a thin shape. Target Weber contrast ranged from +/- 19%. Observers first decided whether the shape was fat or thin and then whether the target was lighter or darker than the background. For all correct shape response trials, the percentage of “light” responses was recorded for each target contrast value. A cumulative Gaussian function was fitted to the resulting data for each inducer polarity and for each kind of shape (fat/thin). Results. There were two main results. First, there was an interaction between shape and inducer polarity for the points of subjective equality. Specifically, when inducers were light, targets inside the shapes were perceived darker than targets appearing outside the shape; when inducers were dark, there was no such dependence. An analysis of the sensitivity parameters showed the same interaction. When inducers were light, targets appearing inside the shapes were discriminated less precisely than targets appearing outside, and when inducers were dark, there was no such dependence. Conclusions. These results suggest that 1) the precision and accuracy of achromatic color judgments depends on interpolated shape; and 2) this effect is much more apparent when the filled-in surface color is dark. These findings further highlight the complex surface-contour interactions that eventuate in the perception of coherent shapes.

26.406 Selective mechanisms for relative phase demonstrated by compound adaptation

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Relative phase of compound grating might be a useful cue to the detection of edges and lines, for which the visual system may have developed specialised detectors. Previous studies have aimed to characterise such detectors by measuring the sensitivity of human observers to changes in relative phase (e.g. Burr et al 1989, *Vis Res* 29: 391-6; Huang et al 2006, *Vis Res* 46: 2069-2081). However, measuring the sensitivity of the overall system does not, tell us about the selectivity of the underlying mechanisms; whether or not selective detectors exist. Here we used compound adaptation to study the detection of relative phase. We created stimuli by combining gratings of $f, 3f, 5f, \dots$ in phases between 0° (zero-crossing align; edge phase) and 90° (peaks/troughs align; line phase). Participants were adapted to edge- and line-phase stimuli simultaneously (one in each hemi-field). The absolute phase of the stimuli was jittered. We then measured whether this adaptation had any differential effect in the two hemi-fields, in terms of the perceived form and contrast of subsequently presented stimuli. Any such differences must result, not from adaptation to the component gratings, but to the compound pattern, since the component gratings in each hemi-field were identical. There was a shift in the point of subjective equality (PSE) for relative phase; intermediate-phase stimuli were perceived as more ‘edge-like’ after adaptation to a line-phase stimulus and vice versa. Similarly, there were PSE shifts in the contrast domain, indicating a lower apparent contrast of probes with the same relative phase as the adaptor. These effects can only be attributed to the differences in the relative phase (alignment) of the component sinusoids and are consistent with the existence of a neural mechanism responding selectively to stimuli of particular relative phases.

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26.407 Response priming by illusory contours

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Whereas neurophysiological studies have shown that illusory contours are signaled in early visual areas at very short latencies, it has been concluded from behavioral studies using backward masking that illusory-contour

stimuli have to be present unmasked for at least 100 ms to be perceived and discriminated. In three experiments, we employed a response-priming paradigm where participants responded to the shape or orientation of illusory and real-contour targets preceded by illusory and real-contour primes at stimulus-onset asynchronies up to 129 ms. Participants either responded to the illusory contours or to the real-contour inducing lines. Priming effects were similar for illusory and real contours, and also across contour type. The effect was fully present in the fastest responses. We conclude that illusory contours can rapidly trigger associated motor responses even under conditions of heavy masking, suggesting that illusory contours are extracted during the first wave of processing traversing the visuomotor system.

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26.408 Contextual Modulation of Contour Detection is Altered in Schizophrenia

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Contour detection is an important step in early visual processing that facilitates figure-ground segmentation and object recognition. Patients with schizophrenia show abnormalities in early visual processing, and contour detection deficits have been observed in those with this disorder. It has recently been shown that during contour detection, nearby elements that are not part of a contour can influence detection thresholds, an effect referred to here as contextual modulation. The valence of this modulation depends on the relative orientation between contour elements and flankers, and agrees with known orientation selective surround suppression (OSSS) effects. It has also been shown that the OSSS effect is diminished in subjects with schizophrenia. However, it is currently unknown how deficits in OSSS in schizophrenia may influence contextual modulation by flanking elements during contour detection. Therefore, we measured contour detection thresholds in healthy adults and those with schizophrenia in a psychophysics experiment. Stimuli consisted of an array of Gabor elements with a vertically oriented group of elements forming a target contour to the left or right of fixation. Thresholds were obtained by determining a subject's tolerance to jitter in the orientation of target elements. Stimulus context differed between conditions, and was defined by the relative orientation between contour elements and flankers (5 Gabors flanking left & right of both possible target locations). Within subject groups, thresholds for randomly or orthogonally oriented flankers are significantly higher than for parallel flankers. In general, subjects with schizophrenia performed better on the task than healthy controls, with a significant increase in performance in the orthogonal condition, relative to randomly oriented flankers, that was not observed in controls. Increased performance in the orthogonal condition constitutes a context-specific visual processing abnormality during contour detection, and suggests broader tuning of orientation-dependent lateral masking effects in schizophrenia.

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26.409 The contribution of colour and spatial frequency cues to contour integration

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Cue combination of orientation collinearity with additional colour or spatial frequency cues was studied within the pathfinder paradigm. Human subjects had to detect target contours, embedded in cluttered backgrounds, and identify their shape. Single cue targets were defined by either orientation collinearity of contour elements, feature contrast in colour, or in spatial frequency. Double cue contours were combinations of element collinearity with one of the feature contrast cues. Cue summation, conceived as the saliency gain due to multiple cues, was measured in a 2AFC task and tested against predictions derived from probability summation and linear summation. Cue summation with spatial frequency contrast significantly exceeded the independence prediction and also surpassed linear summation in a number of conditions. Cue summation with colour contrast, however, only scarcely exceeded probability summation and always fell below linear summation. For both the colour and spatial frequency cue, identification performance benefitted more from cue combination than detection.

Results thus suggest distinct saliency inducing mechanisms in contour integration, one that subserves object detection, the other mediates form completion and shape identification.

26.410 Closing the Gap: Sensitivity to Real and Illusory Contours in Patients treated for Bilateral Congenital Cataracts

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Early visual deprivation impairs many aspects of vision, including the perception of global form and motion (Lewis et al., 2002; Hadad et al., submitted). We examined the effect of abnormal early visual input on later sensitivity to shapes formed by real and illusory contours. Patients treated for bilateral congenital cataracts (M age = 21.6 years, range = 12.8 - 30.1 years; n = 9) and comparably aged visually normal controls (n = 14/age group) discriminated fat from skinny shapes formed by real and illusory contours at high support (0.5) and low support (0.2) ratios (the ratio of the physically specified contour to the total edge length). The angle of rotation of the shapes' corners increased or decreased over trials, producing fatter or skinnier shapes. We defined threshold as the smallest angle of rotation for which the shape was discriminated accurately as fat or skinny. Testing was monocular, with the patients' results divided into those for the better and worse eye, as defined by acuity and alignment history. Z-scores, based on age-appropriate norms, indicated a large deficit in the perception of both real and illusory contours in the worse eye (all $p < 0.05$) but not in the better eye (all $p > 0.10$) of deprived patients. To account for the deficit in processing real contours, we calculated interpolation cost (interpolated contour minus real contour divided by real contour). For each eye of patients and controls, we found a significant effect of support ratio, with higher support associated with lower cost (all $p < 0.001$). However, interpolation cost did not differ significantly between patients and controls for either eye (all $p > 0.10$). Therefore, although patients with early visual deprivation show overall deficits in sensitivity to shape, there is no additional loss in sensitivity to shapes formed by illusory contours.

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26.411 Functional organizations underlying illusory and kinetic contour processing in extrastriate visual cortex V4d of macaques

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Visual Illusions have proven to be a fruitful strategy to investigate the constructive nature of vision, however the neuron substrate underlying illusory and kinetic contour processing has been surprisingly difficult to localize in visual pathway. With our home made in vivo dual Optical Imaging rig, the functional organizations of V4d in 4 macaques have been systematically charted for abutting line illusory contour (IC) and white-noise defined kinetic grating (KG) stimuli. We have observed clear modular assemblies of cells in V4d responded to IC and KC stimuli. By closely examination of the spatial alignments of these orientation domains activated by moving luminance sinusoidal gratings (sLG), IC and KG through pixel by pixel comparison, we found that the orientation domains in V4d activated by IC stimuli were closely in register with those activated by sLG stimuli of the same orientation. In contrast, the movement of white-noise kinetic gratings (KG) produced orthogonal orientation domains instead. By directly comparison with real contour stimulus of sinusoidal gratings, the signal strengths were relatively much weaker for both IC and KG responses in V4d as expected, with KG the weakest. Our observations demonstrated directly that the functional organization and cortical mechanism in V4d for processing IC and sLG is possibly with the same neuronal mechanism in a manner of form-cue invariance; but not for KG stimuli that might involve different neuron populations from segregated processing channels. Thus these data indicate that extrastriate V4 of the ventral stream in macaque is more likely the key converging station for IC processing, but not for motion defined contours which might be represented in MT of dorsal stream or appear as an emergent feature that requires ongoing interactions with MT in macaque. Correspondence: w.wang@ion.ac.cn

26.412 Probe detection reveals a border-to-interior scheme for perceiving a grating-texture surface

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It has been proposed the visual system represents a texture surface by first constructing the boundary contour (BC) and surface texture adjacent to the BC, whereupon the process spreads interiorly until completion. To further verify this border-to-interior hypothesis, we tested the prediction that representing the central area of a disc image takes less time if the disc diameter is small. We used a monocular boundary contour (MBC) rivalry stimulus, comprising of a grating disc surrounded by orthogonal grating square in one eye and the same orthogonal grating square in the other eye. With this stimulus, the MBC disc is rendered dominant for surface representation while the orthogonal grating in the other eye is suppressed. We measured detection of a monocular Gabor probe (20 msec) presented at the center of the MBC disc (1.5 or 3.0 deg diameter), or its corresponding retinal location, at various SOA between the probe and MBC rivalry stimulus (30, 50, 80, 120 msec). If the surface representation of the MBC disc spreads inwardly from the MBC (border) to the disc center, the central disc area is expected to be completely represented at a shorter SOA when the MBC disc is small. This will be revealed as a reliable threshold difference between the two eyes (interocular suppression). Our results confirm the prediction. For example, at the 30 msec SOA, there is a significant interocular suppression with the 1.5 deg stimulus, which does not occur until 80 msec with the 3.0 deg stimulus. Besides confirming the border-to-interior hypothesis, the observation that interocular suppression occurs as early as 30 msec suggests the inhibitory mechanism becomes effective almost immediately upon stimulus onset and is much quicker than previously thought (150 msec).

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26.413 Transilience Induced Blindness

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Purpose: The targets of Motion-Induced Blindness (MIB) are generally small in size. We investigate the disappearance of the large target figure whose diameter subtends 14 degree at the periphery of 14 degree. We devised the novel inducing stimuli that repeated the transilient change while smooth alteration. We coined the disappearance Transilience Induced Blindness (TIB). The results suggested the luminance contrast asymmetry and orientation anisotropy. The textured patterns would also slip away from our consciousness.

Methods: Experiment1: At the upper and lower 14 degree eccentric positions, the 2 yellow filled circles were presented for the targets. At the concentric positions the unfilled blue circles which repeatedly shrank smoothly from 22 degree to 18 degree in one second and jumped back to 22 degree. Experiment2: The inducing unfilled circles were stationary of 28 degree diameter which altered the luminance from white to black in 3 seconds and jump back to white. Some other variants of target figures were investigated.

Results: The subjects reported the disappearance of the targets and suggested an anisotropy that targets at vertical meridian positions were preferable to the horizontal arrangements. The luminance contrast had also an asymmetry such that the brighter target on the darker background condition was preferable to the opposites. The concentric circles or radial line segments were also disappeared. TIB needed the steady adaptation. If the targets even slowly moved or changed colors or size at the moments of transilience, TIB was readily destroyed. The transilience could lead a conjecture that the mechanisms of TIB would include the interactions between time domain gain control delay and the stationary border detectors.

Conclusions; The targets either upper or lower, or both were disappeared spontaneously after a several second adaptations as fixating the screen center. The disappearances were transient and synchronized to the inducer transilience.

26.414 Selectivity for contrast polarity in contour integration revealed by a novel tilt illusion

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We studied a novel illusion of tilt inside a checkerboard pattern due to the role of contrast polarity in contour integration. The preference for binding of oriented contours elements having same contrast polarity, over binding of opposite contrast polarity ones (CP rule), has been firmly assessed by previous research, and it is phenomenically shown by several visual illusions. In three experiments we have investigated how the binding effect is affected by luminance contrast value, reliability of contour elements, and distance among them. Experiment 1 showed that the effect is stronger when the luminance contrast values of the elements are more similar, and when their absolute values are higher. In Experiment 2 the strength of the illusion was found to decrease steeply as reliability of the elements decreased. The CP rule effectiveness, thus, seems to depend on good continuation, and to be overcome when this is broken. It might be that the contrast polarity signals intensity decreases in the association field the more the relative orientation of the contour elements deviate away from linearity. In Experiment 3 we estimated the distance threshold and it was found to be smaller than the one found for other illusions, arising with collinear fragments. This seems to show that the contrast polarity signal inside the association field of a contour unit loses strength more steeply along non collinear orientations, than collinear ones.

26.415 Neural Correlates of the Poggendorff Illusion driven by Illusory Contour: an fMRI Study

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The Poggendorff illusion is a well-documented geometric illusion that involves the brain's perception of the interaction between oblique lines and object contours: an oblique line is apparently misaligned once interrupted by two parallel contours (Fig. 1A). This illusion occurs even when the parallel contours are defined subjectively or illusorily. In this fMRI study, we adopted a 4 (type of stimuli: Poggendorff illusion under real contour and its corresponding control condition; Poggendorff illusion under illusory contour and its corresponding control condition) by 4 (degree of angle between the oblique line and the two vertical contours: 22.5°, 45°, 67.5°, and 90°; Fig. 1) factorial design to investigate the neural correlates of Poggendorff illusion induced by real and illusory contours. By computing the parametric modulation effect of the angle for different type of stimuli, we found that, as compared with the control conditions, the two types of Poggendorff illusion conjointly activated the right intraparietal sulcus (IPS; Fig. 2A). Moreover, the right IPS was involved in the neural interaction between the two types of illusions by showing higher neural activity in the illusory than in the real contour condition (Fig. 2B). Taken together, our results suggest that the right IPS is responsible for constructing the Poggendorff illusion driven by illusory contours.

26.416 Lazy neurons for good shape - Neural energy minimization models for perceptual curve completion

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The (modal or amodal) completion of curves between two visual inducers is a fundamental perceptual organization process whose understanding requires combined multidisciplinary effort. Since the exact shape of completed curves is difficult to measure psychophysically, better modeling would combine evidence from all of the psychophysical, neurophysiological, and computational vision sciences. Here we suggest a new framework based on the abstraction of the curve completion process directly in the visual area where it presumably occurs (namely, the primary visual cortex-V1). In particular, following both physical and Gestalt arguments, we theorize that the perceived completed curve is formed by neural activation patterns in V1 that obey proper energy minimization criteria.

Since suitable abstraction for V1 is a known mathematical space - the tangent bundle $R^2 \times S^1$ - we turn to model various energy criteria of activation patterns in V1 via formal energies of curves in $R^2 \times S^1$. Following our proposed theory, we then seek the (tangent bundle) curves of least energy that

match the boundary conditions defined by the inducers. Two biologically-plausible energies are particularly appealing in this context. First, we investigate the fundamental energy determined by the mere number of active cells in the pattern, or abstractly, by the length of the corresponding tangent bundle curve. Second, considering also the cost of neural connections, we explore a neural energy analogous to the bending energy of elastic rods, to model curve completion via elastica[Euler 1744] in the tangent bundle. We show how these models progressively improve completion predictions and how they entail visual properties that match reported psychophysical findings. Unlike the bulk of previous modeling work, our approach requires no prior assumptions about the shape of the completed curve, and it is the first to predict that the curvature of the inducing elements (in addition to their position and orientation) is essential for perceptual curve completion.

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26.417 How the unseen informs us about the seen: Metacontrast masking with texture-defined second-order stimuli

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What is known about contour and surface feature processing in the primate visual system applies mainly to first-order stimuli, such as objects defined by wavelength- or luminance-contrast differences. It is unclear whether the same processes and their properties apply to perception of second-order stimuli, such as shapes created in random-dot stereograms or contours defined purely by surface texture differences. Presently, evidence indicates that processing and perception of first- and second-order features at least partially relies on separate neural mechanisms. However, the similarities and differences between first- and second-order feature and object processing have not yet been fully established. We employed a visual masking methodology to examine how the human visual system handles contours and surfaces of texture-defined second-order stimuli. The experiments revealed that (1) both the monotonic type A as well as the standard nonmonotonic (U-shaped) type B metacontrast effect, which has been extensively examined with first-order stimuli, can also be obtained with texture-defined second-order stimuli; and (2) that neither the size nor orientation contrast between texture elements defining the target, mask and background stimuli had a significant impact on the magnitude or shape of metacontrast, unlike analogous contrasts with first-order stimuli. In light of these and previous findings, evidence suggests that the metacontrast suppression mechanism can be activated not only by first- but also by second-order (cyclopean and texture-defined) features and objects. This additionally indicates that first- and second-order contours are processed in a similar manner; hence, possibly, by a similar neural mechanism. However, since neither size nor orientation contrast between texture elements defining the target, mask and background stimuli had a significant impact on the magnitude of metacontrast masking in the present experiments, this suggests that there also may be processing of second-order contour and surface features that is distinct from processing of first-order contours and surfaces.

26.418 Spatial Range of Contour Integration in Schizophrenia

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Perceptual organization impairments in schizophrenia have most commonly been demonstrated in contour integration (CI) tasks. Here, we tested the hypothesis that CI impairments become more pronounced as the distance between integrated elements increases. In the first experiment, patients (n= 30) and controls (n=20) were presented an array of Gabor elements, a subset of which could be integrated into an oblong shape. The task

was to determine whether the shape pointed up, down, right or left. There were two spacing conditions, corresponding to whether the Gabor elements comprising the contours were spatially separated by 4.5 or 9 wavelengths. For each condition, we employed the method of constant stimuli and modulated delta—the ratio of background element spacing to target element spacing (where higher delta creates an easier task). Accuracy was computed for each delta level and a three-parameter Weibull function was fit to the data for each spacing condition. Both groups performed better (lower delta thresholds) when the target elements were separated only by 4.5 wavelengths. The effect of group was not significant, but there was a trend for the magnitude of patients' performance decrement relative to controls to increase in the 9 wavelength condition. In the second experiment, the shapes pointed only left or right (to reduce key-press errors). In addition, the range of delta values was restricted to the steepest part of the curve (to improve threshold estimates) and the number of trials per delta level was increased (to improve fit). With a new sample (36 patients, 25 controls), we observed main effects of target-spacing and subject group, but no significant interactions. These data suggest that the previously demonstrated CI impairment in schizophrenia is due to factors other than an impairment in integrating features at larger distances, although spatial range may affect level of CI impairment under some conditions.

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26.419 Selective Filling-in of Large Artificial Scotoma

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Purpose: On the Motion-Induced Blindness (MIB), the target is identified as the perceptual or artificial scotoma. The question is whether the scotoma permits the area to filling-in. We devised an artificial scotoma which subtended 5 degree or more induced by the repeated transilient changes of the inducer and examined the filling-ins.

Methods: Experiment1: At the upper and lower 7 degree eccentric positions, the 2 green filled circles of 7 degree diameter were presented which would eventually disappear on the red background. The inducer was the unfilled white circles which shrank smoothly from 11 degree diameter to 9 degree in one second and jumped back to 11 degree. Experiment2: The background was composed of gray and black areas. The left and right half or the inside and outside of the center circle of 7 degree radius were examined. Experiment3: The white vertical meridian line and the unfilled circle of 7 degree radius which passed under the centers of the targets were presented. Experiment4: The many vertical lines or the dynamic random dots which were the optimal stimuli for filling-in were examined.

Results: The targets were disappeared spontaneously after several second adaptation. Experiment1: The color fill-in was positive and worked instantaneously. Experiment2: The subjects reported an ambiguous boarder between filled-in gray and black area. Experiment3: The line segments were never connected in the target area after the disappearance. Experiment4: The filling-ins were totally negative. Subjects observed uniform black areas. The failure of the line segments filling-in would be due to the large size of the targets. The negative texture filling-in could lead a conjecture that they would really need a few seconds observation.

Conclusions; We found that any uniform color would fill-in, Neither the simple line segments passing under the targets nor the fine textures could never fill-in.

Attention: Endogenous and exogenous

Saturday, May 7, 2:45 - 6:30 pm

Orchid Ballroom, Poster Boards 420 - 432

26.420 Exogenous cue size modulates attentional effects

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A dual-task experiment was designed to determine whether attentional effects are modulated by the size of the exogenous cue. A random-dot kinematogram (RDK), containing 100 white dots, was presented in each visual quadrant. In one RDK, the dots moved in a coherent direction for 200ms. On 50% of the trials, one of the dots in one RDK turned red. Participants reported the direction of coherent motion and the location or absence of the colour probe, and accuracy was measured. In the first experiment the exogenous cue was a luminance-change frame surrounding the RDK, 'flashing'

for 80ms. The cue was uninformative for both the location of the coherent motion and the location of the colour probe. A validity effect was found for the motion discrimination, but not probe localisation. In the second experiment, the cue frame only surrounded the central region of the RDK, to spatially match the probe stimulus. The red dot probe was confined to the same central region of each RDK. A validity effect was evident for both tasks. A third experiment was conducted to ensure that the difference between Experiments 1 and 2 was due to the cue, rather than probe location uncertainty. The cue surrounded the RDK as in Experiment 1, but the probe was confined to the central portion of the RDKs as in Experiment 2. As in Experiment 1, there was only a validity effect for the motion discrimination task, confirming that exogenous spatial attention is affected by the size of the cue. These results suggest that the size of the exogenous cue must match the size of the stimulus in order to have an effect.

26.421 Differential effects of endogenous and exogenous attention on second-order contrast sensitivity

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Covert spatial attention increases contrast sensitivity for first-order, luminance-defined patterns, at the attended location, while reducing sensitivity at unattended locations relative to a neutral-attention condition. Humans are also sensitive to second-order patterns, e.g., spatial variations of texture. Second-order sensitivity is modeled using a cascade of a linear filter tuned to one of the constituent textures, a nonlinearity (rectification) yielding stronger positive responses to regions containing that texture, and a second spatial filter sensitive to texture modulations. Here, we assessed whether and how exogenous (involuntary, transient) and endogenous (voluntary, sustained) attention affect sensitivity to second-order, texture-defined contrast. Methods: Stimuli were orientation-defined, second-order, sine-wave gratings at two of four 5° isoecentric locations. A vertical or horizontal grating was used to modulate between two carrier textures (gratings with higher spatial frequency, oriented at ±45°). Second-order modulator and first-order carrier phases were randomized. Observers judged the orientation (vertical or horizontal) of the modulator; performance was measured as a function of modulator contrast. Exogenous attention was manipulated with a brief uninformative peripheral pre-cue adjacent to one of the stimulus locations. Endogenous attention was manipulated with a longer-lasting informative central pre-cue. Target location was indicated by a post-cue, yielding valid (pre-cue matched post-cue; exogenous: 50%, endogenous: 67%) or invalid (mismatched; exogenous: 50%, endogenous: 33%) cue conditions. In both experiments, a neutral cue (33% of total trials) indicated that the target was equally likely to appear at any location. Results: Both exogenous and endogenous attention increased second-order contrast sensitivity at the attended location, while decreasing it at unattended locations, relative to the neutral condition. Exogenous attention increased second-order contrast sensitivity for high (1 cycle/deg), but not for low (0.5 cycle/deg), second-order spatial frequency patterns. However, endogenous attention enhanced contrast sensitivity for both high and low second-order spatial frequency patterns, supporting the view that endogenous attention is more flexible.

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26.422 Exogenous cuing improves perceptual performance

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Behavioral evidence is presented to support the claim that cuing can improve perceptual performance, using a measure that is not confounded by response bias. We used an orientation matching task to gauge the quality of participants' visual percepts. Participants (N = 20) were instructed to maintain focus on a central fixation cross while an exogenous cue and a randomly rotated Gabor patch stimulus were briefly presented on a screen. Participants then rotated a line to match the orientation of the stimulus. Accuracy was emphasized and auditory feedback was provided. Stimuli were presented left or right of center, and squares around those stimulus locations served as cues. Twenty percent of cues were neutral (cue on both sides), 40% were valid, and 40% were invalid. There were five blocks of 150 trials each. Stimuli appeared 60 ms following cue onset and remained on the screen for 60 ms. The response line appeared 300 ms after stimulus offset. Validly cued trials (mean error 10.3 degrees) were more accurate than

invalidly cued trials (11.2 degrees), with neutral trials intermediate (10.6 degrees). Though participants were instructed to focus on accuracy, there was also a robust effect of cuing on response time. Judgments for validly cued stimuli (mean response time 846 ms) were reported more quickly than neutral trials (878 ms), and neutral trials were faster than invalidly cued trials (916 ms). Our accuracy results can be explained neither by response bias nor perceptual bias. We interpret our results to indicate an effect of cuing on perceptual quality.

26.423 Involuntary attention improves perception by resolving competition

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A widely known effect of attention on visual processing is the enhancement of perceptual processing at the attended location. When a cue that is informative about the location of a target is presented before it, target perception is enhanced, as reflected by improved identification accuracy. While such effects of voluntary attention on perception are robust, it is unclear whether perceptual processing can also be modulated when a non-informative peripheral cue guides attention involuntarily (Carrasco et al., 2004; Prinzmetal et al., 2005).

We hypothesized that the controversy about the effect of involuntary attention on perception originates from the different stimulus conditions employed across studies. Specifically, studies demonstrating the effect of involuntary attention on perception included distractors with the target, whereas no such distractors were present in studies that reported no effect of attention. It is therefore possible that involuntary attention affects perception only under distractor interference.

We tested this hypothesis in a spatial cuing paradigm. In separate experiments, participants reported the identity of a letter or the orientation of a tilted grating. On any given trial, the target letter or grating could be presented by itself or with distractors of the same stimulus category as the targets. Involuntary attention was guided by a peripheral cue that was non-informative of the target location or identity. We found significant effects of involuntary attention on target identification accuracy only when distractors were present, with no effect of attention without distractors, even when the target was perceptually degraded. These attentional effects were not due to reduced location uncertainty or decision bias because uncertainty of the target location was eliminated by a local mask immediately following the target or by a response cue that indicated the target location at stimulus onset.

These findings suggest that involuntary attention improves perception specifically by resolving target-distractor competition.

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26.424 Voluntary attention modulates motion-induced mislocalization

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When a test is flashed on top of two superimposed, opposing motions, the perceived location of the test is shifted in opposite directions depending on which of the two background motions is attended. A transparent layer that was composed of black splotches rotated in one direction, while the transparent layer that was composed of white splotches rotated in the opposite direction. Rotation direction reversed for both transparent layers simultaneously every 1200 ms. The test disks were in fact always vertically aligned, and appeared for ~50ms starting at the moment when the white transparent splotch layer began rotating CW and the black transparent splotch layer started rotating CCW. When the white splotch layer was attended, the disk pair appeared slanted to the right. When the black splotch layer was attended, the disk pair appeared slanted to the left. Because the stimulus remains unchanged as attention switches from one motion to the other, the effect cannot be due to stimulus-driven, low-level motion. A control condition ruled out any contribution from possible attention-induced cyclotorsion of the eyes. This provides the strongest evidence to date for a role of attention in the perception of location, and establishes that what we attend to influences where we perceive objects to be.

26.425 Temporal Expectancy, Framing Effects, and the Modulation of Inhibition of Return

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In the exogenous attention paradigm, the cue recruits involuntary attention, as it does not where the target will appear. It recruits voluntary attention as it does predict when the target will appear (i.e., with equal numbers of trials for each cue-target interval (CTI), there is a greater probability of the target appearing with each passing CTI.) Recent studies eliminated volitional temporal preparation but produced conflicting results regarding the contribution of volitional attention on inhibition of return (IOR) in detection tasks. Tipper and Kingstone (2005) increased the number of catch trials and found reduced IOR. Gabay and Henik (2008) used aging, non-ageing, and accelerated ageing foreperiods and found no modulation of IOR. In the multiple location IOR paradigm, at least three locations are cued in sequence prior to target appears. Of interest is whether the increasing magnitude of IOR found at the most recently cued location as the number of cues increases, reflects volitional attention. In E1, we eliminated volitional temporal preparation by varying the number of trials such that the probability of a target appearing was: 50% after cue 1, 25% after cue 2, and 12.5% after cue 3. Subjects were informed of the probabilistic contingencies yet the results showed no modulation of IOR (i.e., on a 3-cue trial, IOR was largest at the most recently cued location and smaller for less recently cued locations). However, we considered the possibility that framing target appearance in terms of probability rather than the frequency may not have been optimal. In E2, we framed the instructions in terms of frequency (i.e., on 50 of the 100 trials, the target will appear after cue 1 etc). Interestingly, the results showed that IOR was equivalent at all cued locations, suggesting that IOR is fundamentally a reflexive event that can be modulated by volitional attention. predict

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26.426 Voluntary production of visual items modulates transient attention twice

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Previous studies have shown that the voluntary production of visual stimuli modulates visual attention. However, little is known about the attentional mechanisms underlying this effect. To clarify this issue, the present study examined the time required for the accurate identification of visual stimuli voluntarily produced by participants' key presses. Participants observed a stream of numerals presented at the rate of 20 items/s and identified letters embedded in the stream. Under the voluntary condition, the numerical stream switched to the letter stream immediately, 100, 200, 300, 400, 600, or 800 ms after the participants' key presses. Under the automatic condition, the switch from the numerals to the letters occurred automatically so that participants were unable to anticipate the onset of the letters. Participants were asked to report the first four sequential letters. The results showed that the second letter was more frequently reported than were the first, third, or fourth letters under both the voluntary and the automatic conditions. These results suggest that the transient attentional response is triggered by the appearance of a critical item after a delay of a few tens of milliseconds. Importantly, the second letter was reported more frequently when the switch occurred 100, 400, or 600 ms after voluntary production than when the switch occurred automatically. The rates of reporting voluntarily produced letters under the other delay conditions did not differ from those under the automatic condition. Thus, we conclude that voluntary production of target letters causes two phases of transient attentional modulation; the first increases rapidly and decays quickly, and a second similar wave occurs approximately 500 ms after the onset of voluntary production.

26.427 What Stimulus Attributes are Enhanced by Attention?

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In studies of the behavioral effects of attention, performance is often rendered difficult by degrading the stimulus in some way (brief stimulus presentations, addition of noise, reduction of contrast). The goal of this research was to determine which stimulus attributes are affected by voluntary spatial attention. Subjects performed orientation judgments on oriented Gabor

patches, and spatial attention was directed using spatial-cueing paradigms. In the first experiment, an anti-cueing design was used (Posner, Cohen, & Rafal, 1982): a peripheral cue at one location indicated a higher probability of the target appearing at the opposite location. Better performance at the opposite location at long cue-to-stimulus intervals is the result of voluntary attention, whereas better performance at the cued location at short intervals indicates involuntary attention. Visual "white pixel noise" was added to the stimuli. Orientation discrimination thresholds were affected by voluntary but not by involuntary attention. In experiments 2-4, a direct predictive cue was used (Posner, 1980). These experiments determined the contributions of external noise and the size of the orientation discrimination on attention effects. Experiment 2 compared predictive and nonpredictive cues with no external noise in a fine orientation discrimination. Experiment 3 replicated this experiment with fiduciary markers (e.g., Gould et al., 2007) to ensure that there was no location uncertainty. In Experiment 4, the orientation difference was large, but performance was limited by adding pixel noise. We found significant effects of voluntary attention, both with fine orientation judgments with no external noise and also with coarse judgments and external noise. Finally, unlike the previous experiments, limiting performance by lowering contrast showed no effects of attention when the orientation discrimination was large. These results suggest that attention enhances both fine and coarse orientation discriminations, even in the presence of noise, but not when performance is limited by contrast.

26.428 Top-Down And Bottom-Up Modulation Of Retinotopic Activity In Temporal And Parietal Cortex

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We used fMRI to study the modulation of retinotopic maps in human cortex by top-down

and bottom-up attention. We presented point-light biological motion or scrambled control stimuli in a phase-encoded polar angle mapping paradigm. The background of the stimuli was either empty, or contained the opposite stimulus type. Subjects fixated and always ignored the peripheral stimuli as they performed a low-load (respond on red cross) or a high-load (respond on upright yellow or inverted green cross) task at fovea. Even in the absence of attention, and the presence of competing stimuli in the rest of the visual field, multiple brain areas, primarily in occipital and temporal cortex, still responded retinotopically to the stimuli. There was no effect of attentional load on fovea on these responses; i.e., the stimuli drove retinotopy regardless of how strongly attention was directed elsewhere. Consistent with Saygin & Sereno (2008), parietal and frontal maps were not strongly active in the absence of top-down attention to the stimuli. Although stimulus effects on retinotopic responses were subtle (and could easily be swamped by responses to the mere presence of stimuli, hence our background manipulation), lateral temporal retinotopic regions, including the superior temporal sulcus (STS), responded preferentially to biological motion, even when these stimuli were task-irrelevant. A similar pattern was seen in primary visual cortex. Overall, it appears that parieto-frontal retinotopic maps are highly sensitive to, possibly even dependent on top-down attention. Occipital and temporal maps on the other hand, maintain stable retinotopic representations under a variety of conditions. Lateral temporal areas including the STS show preferential responses to the biological motion stimuli even when they are task-irrelevant. Thus, retinotopic maps in different areas have distinct functional properties, likely reflecting their roles in real life vision and attention, for which both flexible and stable representations of space are needed.

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26.429 The time course of saccadic visual selection in patients with parietal damage.

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Previous research with healthy observers has shown that saccades with short latencies are predominantly stimulus-driven, whereas saccades with longer latencies become increasingly goal-driven. The parietal lobes may

play a crucial role in this time course. The aim of the present study was to investigate whether patients with parietal damage have deficits in stimulus-driven processing, goal-driven processing, or both. To this end, we asked a group of patients with unilateral and bilateral parietal lesions and a group of healthy, age-matched controls to make a saccade to one of two oriented lines presented amongst homogeneous background lines. We systematically varied the salience of these lines by changing the orientation of the background elements. Saccadic target selection of the patient group was clearly impaired in the hemi-field contralateral to the main lesion. Although saccades with short latencies were mainly stimulus-driven, performance with longer latency saccades seemed to be at chance level. Performance with stimuli in the hemi-field ipsilateral to the main lesion was similar to that of the controls. We fitted a multinomial model, which allowed us to decompose the individual speed-accuracy functions into the underlying stimulus-driven and goal-driven functions. We found that stimulus-driven processing of stimuli in the more affected hemi-field decreased faster for patients than for controls, whereas goal-driven processing tended to set in later and increase slower. Stimulus-driven processing in the less affected hemi-field was intact. Some patients additionally showed impaired goal-driven processing in the less affected hemi-field. Our results show that stimulus-driven and goal-driven processes are differentially affected by parietal damage, suggesting that both processes are distinctly represented in the parietal lobes.

26.430 Ramped Target Presentation Increases the Magnitude of Location-Based Inhibition of Return

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Previous research (Guenther & Brown, VSS 2008) comparing the effect of stimulus ramping on inhibition of return (IOR) failed to find significant differences between abrupt and ramped conditions when objects were not present in the display. Only when 2-D outline or 3-D cube shaped objects were added to the display did an effect of stimulus ramping emerge. It is possible the absence of a ramping effect without objects could be due to the duration of the ramp used (106 ms). Other studies have used longer ramping durations (200-250 ms) to generate P-biased conditions (e.g., Breitmeyer & Julesz, 1975; Tolhurst, 1975). The present experiments used a longer ramping duration (212 ms). Experiment 1 compared conditions with and without 2-D objects and found strong ramping based effects on IOR in both conditions. In Experiment 1 (as in Guenther & Brown, VSS 2008) abrupt cues were paired with abrupt targets and ramped cues with ramped targets. Therefore, it was possible the observed ramping effects were due to the ramped cues instead of the targets. To rule out this possibility, Experiment 2 compared responses to ramped targets paired with abrupt cues and abrupt targets paired with ramped cues. Across both experiments, IOR magnitude increased for ramped compared to abrupt targets irrespective of cue type. The present experiments illustrate the importance of sensory influences on IOR and support previous research (Guenther & Brown, VSS 2007, VSS 2008; Guenther, Brown, Narang, & Siddiqui, VSS 2009) suggesting stimuli biased towards the parvocellular pathway produce greater IOR than stimuli biased towards the magnocellular pathway.

26.431 Spatial memory increases fixations to targets and onsets in a visual search task

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The study of the relationship between spatial memory and the visual system has led to two disparate theories. Attentional enhancement (Awh, et al., 1998, 1999) proposes that attention enhances processing at the location being rehearsed in memory. On the other hand, saccadic inhibition (Belopolsky & Theeuwes, 2009) suggests that saccades are inhibited from being made towards a memorized location. These tasks have not examined how spatial memory affects the programming of involuntary saccades; that is, saccades made to task-irrelevant objects or events. Here, an experiment was conducted that involved memorizing a single location and then performing a visual search task. In some trials, either the search target or the abrupt onset of a new object coincided with the location in memory. Results demonstrated that more saccades were made to onsets and targets when they coincided with the memorized location versus when they were not.

This supports the attentional enhancement theory, and these findings are discussed in terms of the interaction between the different components of visual working memory, attention, and eye movement systems.

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26.432 Sustained visual attention in the face of distraction: A novel gradual onset continuous performance task

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Sustained visual attention, a fundamental operation that underlies complex processes such as selective attention and visual memory, has classically been studied using continuous performance tasks (CPTs) that require participants to respond (or withhold response) to rare targets in a repetitive stimulus stream. CPTs, however, do not typically elicit vigilance decrements (decreased performance over time), indicating that they are not adequate measures of sustained attention. This could be because CPTs have abrupt stimulus onsets, which may act as exogenous attentional cues and keep individuals on-task. To create a better measure of sustained visual attention and examine the interaction between sustained visual attention and visual distraction, the current study employs a novel variant of the CPT, the gradual onset CPT (GO-CPT). In the GO-CPT, a central face stimulus transitions between individuals at a constant rate (1200ms). In the distractor-present condition, faces are superimposed on background scenes, while in the distractor-absent condition, on scrambled backgrounds. Subjects are instructed to respond to each male face but not to a rare target female (10% of trials). Results from healthy college students show significant vigilance decrements over the task's 12-minute duration: participants make more commission and omission errors and show increasingly variable response latencies over time. Further validating this task as a measure of sustained attention and distraction is the correlation between performance and self-reported mindfulness, or ability to attend to a present task. In the presence of scenes, participants who self-rate as having low mindfulness make more errors, are more variable, and show greater decrements over time than their high-mindful counterparts, indicating a disproportionate effect of distraction on those with a high propensity to experience attention lapses. The GO-CPT is an improved method for studying sustained visual attention and its relationship to distraction and is a potentially useful tool for assessing individual differences in attention.

Attention: Features and objects

Saturday, May 7, 2:45 - 6:30 pm

Orchid Ballroom, Poster Boards 433 - 453

26.433 Cross Modal Object-Based Attentional Guidance

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Over the past decade there has been mounting evidence suggesting that attentional allocation is guided by object representations and that attentional prioritization is the mechanism that gives rise to object-based effects. However, it should be noted that most evidence for object-based guidance has been garnered by studies restricted exclusively to the visual modality. As such, it remains unclear whether object-based guidance of attention is unique to the visual modality or, rather, it reflects a general property of attentional allocation. In the present set of experiments we investigated whether cross modal attentional allocation is also object-based. Participants were presented with a visual display consisting of two rectangles that included two cross-modal cue-target combinations. In the first experiment a visual cue was followed by an auditory target presented at the cued location or at an equidistant location on either the same object or a different object. In the second experiment, an auditory cue was presented followed by a visual target. It was observed that in both cross-modal cue-target pairings (audio/visual and visuo/auditory) objects guided attentional allocation such that same-object targets were detected faster than different-object targets. Additional experiments were conducted to examine whether attentional prioritization is the mechanism guiding cross-modal object-based guidance by introducing probabilistic imbalances such that more targets appeared on different-object locations as compared to same-object locations. The observed pattern of results strongly suggests that object-based atten-

tional guidance is not restricted to the visual modality alone but extends to cross-modal attentional orienting, and that attentional prioritization is the mechanism subserving such guidance. Taken together, these results place further constraints on the mechanisms of attentional allocation.

26.434 Feature-based Selection Differs from Spatial Selection in Visual Working Memory

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Attention toward extrapersonal world has been intensively investigated. However, attention toward internal representations held in visual working memory has remained relatively unexplored. Recently, it has become clear that it is also possible to orient selective spatial attention to internal representations held in working memory (Griffin et al., 2003). Since selection by visual attention can be made not only on the basis of locations, but also on the basis of simple features such as color and shape, we employed feature-based retro-cues to test whether it is possible to use features to direct attention in visual working memory. Sixteen subjects took part in the current experiment and each of them completed all the three kinds of tasks, the color-cue task, the shape-cue task and the spatial-cue task. In each task, subjects were either cued to select a stimulus before the memory array was presented (pre-cue), cued to select an item in visual working memory after the memory array was presented (retro-cue), or given no cueing information (neutral cue). The memory array consisted of four different colored shapes. At the end of the trial, a test stimulus was presented and subjects responded according to whether it matched the item presented at the same location in the memory array. Behavioral performance was modulated by the presence of a feature-based cue in both pre-cue and retro-cue trials, indicating that it is also possible to use features to direct attention in visual working memory. Moreover, we noted a difference in the pattern of behavioral benefits between feature-based selection and space-based selection. Significantly larger cueing effects for pre-cues compared to retro-cues were observed in the color-cue and shape-cue task, while no difference between pre-cues and retro-cues was found in the spatial-cue task. These results might reflect different underlying processes between feature-based selection and spatial selection.

26.435 Rapid and reflexive feature-based attention

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Performance on a visual task can be improved when attention is directed to a relevant spatial location or to a specific feature. Spatial attention can be directed either voluntarily (endogenously) or automatically (exogenously). To date, however, feature-based attention has only been shown to operate endogenously. Here, we show that an exogenous feature cue can also lead to improved performance on a visual task.

Response times were measured as participants detected a target oval amongst a circular array of discs, each with a unique color. A colored square cue was flashed at the beginning of each trial immediately before the onset of the search array, that may or may not have matched the location and/or color of the target oval. The location and color of this cue was randomized with respect to the target so that it had no behavioral relevance. As expected, response times were faster when the cue location coincided with the target location, indicating the classic exogenous cueing effect for spatial attention. However, participants also detected the target faster when the color of the cue matched the color of the target regardless of the cue's spatial location. This is evidence of a novel exogenous cueing mechanism for feature-based attention. Response times were fastest when the cue was valid for both spatial location and color, and a 2x2 repeated-measures ANOVA with spatial and feature cue validity as main factors showed no significant interaction, indicating that spatial and feature-based cueing mechanisms operate independently and additively on search times. Analysis of performance showed no indication of a speed-accuracy trade off.

Our results suggest that even though exogenous cues capture attention to a particular location, the color feature of the cue still provides a rapid and reflexive exogenous feature-based search benefit at unattended regions of the visual field.

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26.436 Global modulation of task-relevant and task-irrelevant dimensions of attended objects

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In a previous fMRI study, we showed that attending to multidimensional objects (i.e. containing color and direction of motion) enhances the neural response to features of the attended object across the visual field, both for task-relevant and task-irrelevant dimensions (Lustig & Beck, in preparation). These results support the integrated competition hypothesis, which proposes that attending to an object enhances relevant over irrelevant stimuli by biasing all neural systems toward the individual dimensions of the attended object, including task-irrelevant ones (e.g., Duncan & Humphreys, 1987). In the current experiment, we investigated whether there are behavioral consequences of global modulation of task-relevant and task-irrelevant dimensions of attended objects. Subjects attended to one of two overlapping multidimensional objects at center and monitored for transient changes in one dimension of the attended object. Occasionally, four items were briefly presented around the central stimulus (two items above fixation and two items below). Each item varied in the degree of similarity to the centrally attended object, either containing i) both task-relevant and task-irrelevant dimensions, ii) only the task-relevant dimension, iii) only the task-irrelevant dimension, or iv) neither the task-relevant nor the task-irrelevant dimensions. On every trial, one of the four peripheral items had a distinctive shape (target); subjects were instructed to locate this target item as quickly and as accurately as possible. Our results indicate that subjects were more accurate at locating the target item when the target contained the same versus the opposite color as the centrally attended stimulus, regardless of whether color was the task-relevant or task-irrelevant dimension. This finding supports the theory that object-based selection results in global enhancement of all dimensions belonging to the attended object and further suggests that this enhancement improves target detection.

26.437 Chroma and luminance interactions in processing of orientation saliency

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Theories of visual attention (Treisman and Gelade, 1980; Koch and Ullman, 1985; Itti, Koch and Niebur, 1998) suggest that the computation of visual saliency, at its early stages, relies on local feature contrasts (e.g. color contrast, orientation contrast) and is carried out separately and independently within each perceptual dimension (e.g., color, orientation, motion, etc.). These theories agree with the general view that different dimensions of visual information are segregated at early stages of visual processing into largely independent visual pathways (Livingstone and Hubel, 1987). This segregation, however, is not clear-cut. For example, many of the cells in the primary visual cortex exhibit similar orientation tuning for both luminance and equiluminant oriented patterns (Johnson and Shapley, 2008). In this study we explore possible interactions across perceptual domains in the computation of orientation saliency. Trials in our experiments were composed of textured backgrounds, whose initial presentation was followed by a brief (150 ms) superposition of the same texture with a single target bar, two target bars, or no bar at all. Bars were oriented parallel or orthogonal to the texture and subjects' 3AFC task was to report the number of bars observed (Mokeichev, Segev and Ben-Shahar, 2010). In the first experiment, the textured backgrounds and the bars were isoluminant, and a highly significant saliency effects were observed for bars with orthogonal orientation with respect to the background. These results are in agreement with previous reports of isoluminant orientation pop-out effects (Luschow and Nothdurft, 1992). In the second experiment, the textured backgrounds were isoluminant, and the bars were defined by luminance modulation. Here again, highly significant orientation saliency effects were observed. These results point toward interactions between color-defined and luminance defined orientation processing and suggest orientation as a perceptual dimension which is independent of its defining attributes - whether luminance or color.

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Robotics Research, the Zlotowski Center for Neuroscience, and the Lynne and William Frankel Center for Computer Science at Ben-Gurion University

26.438 **Object-based attention: Shifting or uncertainty, reconsidered**

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If attention is cued to one part of an object, it is commonly found that reaction time is faster to a target stimulus appearing at an uncued location on the same object, than to a target at an equidistant location on a different object (Egly, Driver & Rafal, 1994). This finding has been central to theories of "object-based attention" which postulate that objects, not simply locations in space, are the focus of visual attention. As such, it is inherently easier to switch attention between parts of one object than between parts of two different objects. However, Shomstein and colleagues (e.g., Shomstein & Yantis, 2002; Drummond & Shomstein, 2010) have argued that this within-object superiority is simply due to a strategic prioritization of same-object locations for visual search. In principle, within-object superiority should disappear in the absence of location uncertainty. We tested this prediction by presenting targets requiring an E/F discrimination at either an uncued location in the cued object, or an uncued location in a different object, in separate blocks. Contrary to the prediction of the prioritization hypothesis, within-object superiority was as large for separately blocked within- and between-object presentations, as for the more usual randomized conditions. The results favor an inherent advantage for within-object shifting of attention, rather than (or in addition to) strategic prioritization.

26.439 **Object representations maintain attentional control settings across space and time**

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For stable perception it is important to keep track of objects across space and time. It has been proposed that spatiotemporal episodic representations, or object files, serve exactly this purpose. What type of information can be maintained within an object file? We provide evidence that object files retain specific attentional control settings for relevant parts of the objects. In our experiments, the objects were entire visual search displays consisting of a target and multiple distractor items. Target properties (such as location or color) could repeat from trial to trial, which led to selection benefits compared to when the target changed. Importantly, also from trial to trial, the whole display moved in and out of view behind a wall, such that the movement trajectory suggested that either the same, or a different display had emerged. Repetition benefits (or switch costs) for the search target were greater when the spatiotemporal characteristics were consistent with the idea of the same display object re-appearing. This same object benefit occurred for the target location as well as for the target-defining feature (here shape), but not for irrelevant target or distractor features (here color). Subsequent experiments showed that it is the spatiotemporal consistency of the object that is important. A change in object identity did not disrupt the same object benefit, but inconsistent spatial jumps or temporal gaps did. We conclude that spatiotemporal consistency is an important carrier for object representations, and that these representations include specific attentional control settings that have been applied to the same object before.

26.440 **Unitising colour and shape: The effects of stored knowledge on visual selection**

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Models of visual processing allocate a role for serial attention when selection requires the binding of basic features (Treisman & Gelade, 1980). Using visual search combined with eye-movement recordings we challenge this assumption by demonstrating pre-attentive binding of colour and form when these features have a learned relationship. Participants completed a conjunction search task for yellow, orange or purple corn targets in an array of four, eight or twelve, lemon(s), carrot(s) and aubergine(s) distractors. Correctly coloured targets 'popped-out' of the display yielding a shallow search function that satisfied the characteristics of parallel search. In contrast, search for incorrectly coloured targets increased linearly as a function of set-size consistent with attention being deployed serially. In a second visual search experiment we manipulated the prevalence of correctly and incorrectly coloured targets to examine whether effortless detection of correctly coloured corns reflected a 'yellow' attentional set. Corns were

displayed in purple and yellow at a ratio of two-to-one. Eye-movement recordings confirmed that participants adopted a top-down set to search for purple targets, consistent with their probability of occurrence. Despite this, correctly coloured yellow corn targets were detected efficiently and incorrectly coloured purple targets inefficiently. Our findings demonstrate that when colour is a learned property of an item, shape and colour features can be unitised and processed in parallel without focal attention. This is consistent with previous research suggesting that 'diagnostic' colours are stored in an object's perceptual representation (Lu et al, 2010; Tanaka et al, 2001), and extends this to incorporate effects of colour-form associations on guiding visual processing at an early stage. These findings have important implications for understanding efficient conjunction searches and the mechanisms of visual selection.

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26.441 **Object based attention effects disappear when flanking objects are present.**

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When a precue appears in an object, subjects normally identify a subsequent target in the same object faster than one in different object (targets are equidistant from the cue). This response pattern has been interpreted as evidence for automatic object-based attention (OBA). We failed to find OBA effects for two central objects with two outer "flanking" objects (never containing cues or targets) present in the display (Mojica, et al. VSS 2009). We hypothesized that with four objects attention may be allocated more widely than with two, and subjects may not search for the target in the cued object first as they do with only two objects. The four objects in the previous experiment were identical rectangles presented on the same depth plane; they may therefore have been grouped into a single surface. Is grouping into a single surface necessary or is simply having four objects in the display sufficient to eliminate OBA effects? We ungrouped the four objects by using shadows to indicate that the flankers were nearer to the viewer than the central rectangles, and by coloring flankers and central rectangles differently. Again, OBA effects were not observed with flankers present ($p > .74$), although they were found with only two central rectangles ($p < .01$). Thus, simply having more objects in the display may be sufficient to eliminate OBA effects; grouping them into a single surface is not necessary. Because all rectangles were the same shape, however, grouping may still cause the loss of OBA effects. A second experiment tests whether the presence of different shape flankers is sufficient to eliminate OBA. Our evidence that adding two irrelevant objects to the display eliminates OBA supports the view that OBA effects are due to strategic rather than automatic allocation of attention (Shomstein & Behrmann, 2008).

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26.442 **The roles of visual features in the generation of the contextual cuing effect**

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It is well established that repeating the context in which a target appears improves performance in an inefficient visual search task (Chun & Jiang, 1998). Although this effect, referred to as "contextual cuing", was initially attributed exclusively to the development of a memory of the spatial object configuration through repetition, recent studies (Geyer, Shi & Müller, 2010; Huang, 2006) demonstrated that object features (i.e., color) contribute actively to the effect. The present work aims at investigating the relative contribution of two features (namely color and orientation) to the generation of contextual cuing in three experiments. Experiment 1, conducted to provide a baseline data set, is a replication of Chun and Jiang's (1998) Experiment 1 in which participants have to discriminate the orientation of a target surrounded by distractors with various colors and orientations; Experiments 2 and 3 use the same search displays but an object feature is changed after the first half of the sessions and kept changed in the remaining sessions: In repeated trials of Experiment 2, all objects exchange color, while in Experiment 3, objects exchange orientation. The change in object color makes contextual cuing vanish, whereas the change in object orientation does not alter the contextual cuing effect, neither locally (i.e., directly after the manipulation), nor globally (in the entire second set of experimental sessions). In accordance to Geyer et al. and Huang, these results confirm

that not only the location of the objects but also their color is integrated into contextual associations. By contrast, orientation information, probably because it underlies target identification, does not provide a reliable global cue of the target position. Overall, object features seem to play a role in the generation of the contextual cuing effect, but not all of them at the same level or with the same magnitude.

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26.443 Contextual effect in object-based attention when target is integral to the object

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The current study investigated whether contextual effect could be found in object-based attention when task-related features are part of the object using the Egly, Driver, & Rafal(1994)'s cueing paradigm. There were two possible accounts that differently predicted the processing of attended objects. Firstly, attentional spreading account argues object-based attention arises from the enhancement of the representation of an attended object as compared to an unattended object. In contrast, attentional prioritization account asserts the attentional priority in which an attended object is searched earlier than an unattended object. According to a previous research which supports attentional spreading account, a target integral to the object, such as concave stimulus, is known to induce attentional spreading through the object boundaries. We varied the probability of target occurrences in potential locations of the target and measured on the effect of the object-based attention using a concave stimulus. In Experiment 1, participants were instructed to determine whether the target concave was rectangular or circular. The target appeared in the cued location on half the trials. On half of invalidly cued trials, the target appeared either in the high-probability location or in the low-probability location. We found statistically significant effect of object and contextual effect. However, there was no significant interaction between the two effects. In Experiment 2 and 3, participants detected only the presence of the target. The target was present in the cued location on half the trials in Experiment 2 and on 70% of the trials in Experiment 3. The result of both of the experiments also showed a significant object and context effect but not a significant interaction between object and context effect. These results indicate that object and contextual effect of visual attention would depend on the kind of task as well as the sort of stimulus.

26.444 The role of attentional gradients in line bisection performance of hemineglect

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Background: Subjects with hemineglect fail to attend to stimuli on the contralateral side of space. A common finding in hemineglect is an ipsilesional bias in line bisection, a task in which subjects indicate the perceived mid-point of a horizontal line. However, others suggest that patients with parietal lesions may have abnormal spatial representations for contralateral space that account for the ipsilesional bias.

Objective: Our goal was to determine if an attentional shift in healthy subjects was sufficient to create an ipsilesional bias in line bisection.

Method: We created a dual task paradigm, in which subjects had to bisect a line while simultaneously attending to the right side of the display for highly salient moving and flashing coloured targets in an attentionally demanding conjunction search task. We measured ocular fixation distributions as well as bisection judgments.

Results: First, using flashed probes at various locations in space we confirmed in a detection task that our conjunction search task did generate an attentional gradient favouring the right hemisphere. When subjects were engaged in a manual line bisection task concurrent to the right-sided conjunction search task, this created right-biased patterns of ocular fixation similar to those in hemineglect, but did not generate a significant rightward bias in bisection judgments. Accuracy rates for the conjunction task were similar in the probe condition and the dual-task paradigm, indicating that the lack of bisection bias was not due to failure to engage in the conjunction task.

Conclusion: A rightward shift of attention can reproduce neglect-like ocular motor behaviour but not bias in a manual bisection task. This may indicate either that healthy subjects can shift rapidly between task-based spatial attentional sets or that bisection bias in hemineglect patients is generated by additional spatial factors besides an attentional gradient, such as altered representations of space.

Acknowledgement: Funding acknowledgements: PG was supported by an NSERC undergraduate student research award. This project was supported by CIHR grant MOP-81270.

26.445 Sustained attention facilitates change detection, but only in a brief blank duration

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In a normal change-detection task, observers should encode a study image, retain its representation for a time interval, retrieve this representation and compare it with a test image. Many studies indicate that attention is not necessary for retention of a representation, whereas it is essential for encoding and retrieving a representation (e.g., Hollingworth, 2003). In normal change-detection tasks, however, multiple objects are presented within study and test images, making it difficult to examine sustained attention on a single target object. Therefore, the role of sustained attention in change-detection tasks remains unclear. To examine this issue, we conducted an object orientation change-detection task, manipulating an object location between study and test displays (same or different location). Use of a single object should ensure focal attention to that object. In Experiment 1, a study image was presented for 500-ms, and ISI differed (200-ms or 1000-ms). We hypothesized that location shifts require corresponding shifts in spatial attention to the new location, hence should interfere with change-detection. However, location shifts interfered with change-detection performance only in 200-ms condition. Further, in the same location condition, performance was higher in the 200-ms condition than in the 1000-ms condition. In Experiment 2, using a 200-ms ISI, we manipulated the SOA between study and test images (700-ms or 1500-ms) and object location. In this experiment, performance was better for the same (versus different) locations in both SOA conditions. These data are consistent with a suggestion that spatial attention is sustained for a short time interval (Nakashima & Yokosawa, 2010, VSS); they further imply that this time interval is determined by the ISI and not by the SOA. That is, focused attention on an object region is sustained over a subsequent short blank time interval and this facilitates change detection.

26.446 Relation binding deficits during rapid spatial relationship judgments.

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Most objects that we encounter can be decomposed into parts, arranged according to a representation of the spatial relationships among those parts (Biederman, 1987). Our subjective impression is that we immediately and accurately grasp spatial relations when we identify an object. We tested whether these relations are constructed after the individual parts are recognized, by asking participants to identify the parts within an object, or their relations, in a rapidly presented display. We briefly flashed (50ms) a display containing four squares (one per quadrant), each split either horizontally or vertically into two colors. Participants were given a 2-alternative forced choice that tested their encoding of one of three properties: the colors in the cued square, the direction of its split, or the spatial relationship among those colors. The two alternatives were always correct for the two non-tested properties, and participants always knew the relevant property in a given block. In the color block, the foil shared only one of the two colors with the target, encouraging participants to encode the colors of the target. In an orientation block, the foil was split in a different orientation from the target, encouraging participants to encode the orientation of the split within the square. In the spatial relation block, the foil was different from the target only in terms of which color was presented in which half of the target, encouraging participant to encode the spatial relation between the colors. The results showed a relatively high accuracy in the color feature (M=84%) and the spatial structure (M=85%) blocks, but a sharp drop in accuracy for the spatial relation block (M=68%), suggesting that constructing spatial relationship representations requires that object parts enter a time-consuming binding process.

26.447 An Investigation of the Reliability and Relationships among Global-Local Processing Measures

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Global-local stimuli have been shown to be useful for examining a variety of different concepts, such as how human faces are processed (e.g. Hillger & Koenig), how affect can alter an individual's judgement of a stimulus (Fredrickson & Branigan, 2005), how dispositional global/local precedence can alter an individual's perception of time (Lieberman & Förster, 2009), and how dispositional global/local precedence can affect the direction of selective attention (Dale & Arnell, 2010). Throughout the literature, multiple different versions of global-local stimuli have been used, such as traditional hierarchical letters and numbers (i.e. Navon letters), abstract hierarchical shapes, and high and low spatial frequency gratings. However, it is currently unclear how reliable or stable performance is on these measures within individuals over time, and whether these seemingly different measures are tapping into the same underlying process. This study sought to examine the reliability of, and relationships among, three distinct hierarchical measures previously used in research: standard Navon letters with a traditional interference task (e.g. Navon, 1977), hierarchical shapes with a paper-and-pencil free-choice task (e.g. Fredrickson & Branigan, 2005), and superimposed high and low-pass spatial frequency faces with a free-choice task (e.g. Deruelle et al., 2008). Fifty-five undergraduate participants completed all three global-local tasks, and returned 7-10 days later to again complete the same tasks. The degree of global-local bias within an individual was found to be highly reliable in the hierarchical shape task and the spatial frequency face task. Global interference in the Navon task was also reliable, although to a lesser degree. Interestingly, when the relationships among the three measures of global bias were examined, it was found that none of the measures significantly correlated with each other. Therefore, while these measures do appear to be reliable over time, they may be tapping into distinct aspects of global-local processing.

Acknowledgement: NSERC, OIT, CFI

26.448 Object-based Attention and Prioritization Revealed by the Temporal Order Judgment Method

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Recent studies suggest that object-based attentional guidance is a result of attentional prioritization. It is proposed that in the absence of an alternative strategy, items appearing on the same object are prioritized over items appearing on a different object (Shomstein & Yantis, 2002; Drummond & Shomstein, 2008). It should be noted, however, that studies providing evidence for attentional prioritization have relied on spatial cuing paradigms. As such it is not clear whether attentional prioritization emerges from spatial orienting or is independent of it. Here, we use a novel method - the temporal order judgment (TOJ) - to examine whether attentional prioritization emerges in the absence of spatial cuing. Participants were presented with two rectangles oriented either horizontally or vertically. Following a 1s preview time two target stimuli were presented on the same or different objects and participants were asked to report which of the two stimuli appeared first. It was observed, using a cueless TOJ paradigm, that items appearing on the same object show visual prior entry effects; same object stimuli are prioritized by the perceptual-attentional system over stimuli that appear on the different object. In the second experiment we examined whether this same-object prior entry effect is automatic or is a default setting that is abandoned in the presence of an alternative strategy. Here we modified the TOJ paradigm to include twice as many trials on which targets appeared on the different-object as those appearing on the same-object. With a 2:1 ratio of different- to same-object trials there was no longer a prior entry effect present for the same- vs. different-object targets. These results provide strong support for the attentional prioritization hypothesis, demonstrating that priorities are determined independent of spatial orienting. Additionally, these experiments introduce a novel paradigm for measuring object-based attentional guidance.

26.449 Saliency affects feedforward more than feedback processing in primary visual cortex.

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Visual cortex activity is influenced by both top-down attention and bottom-up saliency effects. We used transcranial magnetic stimulation (TMS) over primary visual cortex to investigate how different feature tasks and saliencies influence the timing of visual processing. Participants performed color or orientation judgments on stimuli of the same luminance but different color saliency. A TMS pulse was applied at varying SOAs after stimulus presentation to assess the timecourse of visual suppression. The results showed similar suppression for color and orientation tasks, but differences based upon feature saliency: the more salient stimuli were more resistant to TMS-induced visual suppression than the less salient stimuli, especially at the early SOAs. These results indicate a stronger initial representation of more salient stimuli in primary visual cortex and suggest that different forms of processing may be occurring during early (i.e., feedforward) and late (i.e., feedback) stages of processing.

26.450 Perceptual consequences of feature-based attentional suppression

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In single-unit recording studies, feature-based attention has been shown to enhance the responses of neurons tuned to an attended feature while simultaneously suppressing responses of neurons tuned away from the attended feature (Martinez-Trujillo and Treue, 2004). But how do these attentional modulations occurring at the neuronal level influence perception? While the facilitatory effects of feature-based attention on perception have been widely observed, the role of attentional suppression is not as well understood. Here, we investigated the perceptual consequences of suppression using a 4AFC task in which 4 random dot patterns (RDPs) were presented, one in each quadrant; subjects selected the quadrant containing coherent motion. At the beginning of each trial, subjects viewed either a valid cue that correctly indicated the impending direction of coherent motion, a neutral cue that contained no directional information, or an invalid cue that indicated a direction systematically offset from the actual target direction. We fit our reaction-time and accuracy data using the linear ballistic accumulator (LBA) model (Brown and Heathcote, 2008) in order to assess the effects of attention cues on the speed of sensory information accumulation ('drift rate') during decision making. The average drift rate estimates were highest for valid cue trials and gradually decreased as the offset between the invalid cue and target approached the orthogonal direction of the stimulus (i.e., 90°); intermediate drift rates were observed on neutral trials. In contrast with the neurophysiological data, where suppression was maximal for directions opposite of the attended direction, we observed a recovery of performance when the offset between the invalid cue and target exceeded 90° and approached 180° (see Supplementary Figure). Our data raise the possibility that additional processing steps intercede between attentional modulations observed in MT and the final perceptual experience of the observer.

26.451 Object-based attention: spreading or prioritization?

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The object-based attention effect (OBA) has been explained by two distinct processes: (1) attentional spreading by which attention instantly spreads within the attended object and enhances sensitivity to stimuli within the object boundary, and (2) prioritization by which prior expectation of the target is biased to the cued object. We extended Egly et al.'s (1994) cued spatial detection task in conjunction with a diffusion model to disambiguate the two mechanisms. Participants were required to saccade to the red target among two green distractors, presented simultaneously at three of four ends of a pair of elongated rectangles. One end of a rectangle was cued and the target appeared at the cued end 60% of the time. On remaining trials, the target appeared equally often at the other two locations: on the other end of the cued object (C), or at one end of the uncued object (U). Distractors appeared at the other two locations accordingly. The par-

participants' task was to make a saccade toward the target. Shorter saccade latency and higher targeting accuracy were found when target was in the C than U location, suggesting an OBA benefit on saccade planning. In the context of a diffusion model where evidence accumulates to a threshold, shorter saccade latencies occur in one of two ways: (1) attention causes evidence to accumulate at a faster rate to a fixed bound (attentional spread), or (2) prior expectation biases saccade choice, decreasing the bound but leaving accumulation rate unchanged (prioritization). In the latter case there is a greater probability of false alarms. Our data show that across our four participants (3200 trials each), there were more error saccades toward C than U distractors, consistent with the prioritization account of OBA during saccade planning.

26.452 Change Detection is Better Specifically for Object Properties that Change More Frequently in the Real World

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Previous work has demonstrated that participants more frequently detect changes to objects that are likely to change in the real world (Beck, Angelone, Levin, 2004). Furthermore, it has been shown that across blocks, participants can learn which novel objects are more likely to change and subsequently increase fixations to and detect changes faster for these objects (Droll, Gigone, & Hayhoe, 2007). We used a flicker paradigm to test whether detection was faster for frequently changing objects and whether this advantage was specific to changes that were similar to those observed for the objects in the real world. Participants detected orientation and luminance changes to object arrays displayed in naturalistic scene settings or in hexagonal array. A separate group of judges rated the degree to which each of the objects was likely to be physically moved during typical interactions. We observed faster change detection for objects rated as typically moved in the real world, but only for orientation change detection, and not for luminance change detection. This suggests that the detection benefit of knowledge about probabilities is specific to detecting types of changes that match those typically observed for an object. Thus, in addition to learned probabilities influencing where attention is directed (Droll et al., 2007), object-specific knowledge seems to enhance change detection along relevant stimulus dimensions.

26.453 The simultaneous and involuntary effect of global feature-based attention on motion sensitivity

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Goal: Neural responses to attended feature values such as motion directions are boosted even at ignored locations, in line with the feature-similarity gain principle of Treue & Martinez-Trujillo (1999). Psychophysical and neuroimaging studies have also found effects consistent with the global spread of feature-based attention (FBA) (e.g., Lu & Itti, 2005; Melcher et al., 2005; Serences & Boynton, 2007). However, no study has yet provided direct behavioral evidence for involuntary changes in motion sensitivity that are simultaneous with the deployment of FBA at another location. Methods: Observers (n=13) performed two tasks simultaneously. In the primary task, observers had to detect a speed change in one of two superimposed dot fields moving in opposite directions. In the attended conditions, the direction in which the speed change could occur was precued. In the neutral condition the speed change was equally likely in either direction. At a random time during the presentation of these primary stimuli, two dot fields appeared in the opposite hemifield. One moved randomly (0% coherence) and the other moved coherently either upwards or downwards. The secondary task was to indicate which dot field contained a coherent motion signal, but its particular direction was task-irrelevant. The amount of coherence was varied to estimate 75% correct thresholds. Results: The secondary task did not require observers to discriminate or selectively attend to the particular direction present. Nonetheless, sensitivity was highest when the direction of the secondary target matched the direction cued in the primary task. Comparison to the neutral condition revealed more enhancement of the attended direction than suppression of the unattended one. These perceptual effects of selective attention to motion direction at a distant location occur involuntarily and simultaneously with the deployment of attention, consistent with known neurophysiological phenomena.

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Noise and uncertainty

Saturday, May 7, 2:45 - 6:30 pm

Vista Ballroom, Poster Boards 501 - 508

26.501 Separating Decision Noise and Encoding Noise in Perceptual Decision Making

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Describing the brain's representation of stimuli at various levels of perceptual and cognitive processing remains a challenging task in cognitive research. While Signal Detection Theory (SDT) has provided investigators with measurements of sensitivity and bias at the decision level, it also formally assumes a static decision criterion by absorbing criterion noise into perceptual noise (Wickelgren & Norman, 1966). However, over half a century of research has provided a great deal of evidence contradicting the assumption of a static decision criterion, and correct interpretation of sensory processes requires that criterion noise should be segregated from perceptual noise. A dramatic reassessment of previous research findings based on traditional SDT is suggested by Benjamin et al. (2009) and Rosner & Kochanski (2009). Although extensions of SDT accounting for decision noise have appeared recently, efforts to obtain separate estimates of decision and encoding noise during binary stimulus tasks have relied on significant assumptions about the relationship between various noise components. Here, we develop a new approach based on the "double pass" procedure (Burgess & Colborne, 1988). We first derive and compare representative models capable of independent estimates of the noise components at the decision stage. We then combine a rating procedure with an external noise paradigm employing multiple passes through identical stimulus sets. That is, subjects respond to multiple presentations of identical sets of signal and external noise samples. By providing estimates of observer consistency across passes, these "n-pass" procedures generate sufficiently rich data sets to constrain extended SDT models without making specific assumptions about the relationship between noise components. This combination of theoretical and experimental approaches allows for independent measurements of noise components at several criterion boundaries at the decision stage. Lastly, the analytical framework can also be used to investigate the decision protocol that subjects adopt for a given task.

26.502 Learning of uncertain stimuli transfers from criterion-based to noise-based perceptual decision, but not vice versa

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Making meaningful judgment under various uncertain situations plays an important role in our daily life. It remains unclear whether there is a general neural mechanism dealing with different types of uncertainty. Investigating the transfer of learning effects between different uncertainties paves the way to the fully understanding of this issue. Previous behavioral literatures have shown that uncertainty in decision making can originate from different sources. Converging evidences from fMRI studies have also indicated the neural correlates associated with particular types of uncertainty. In the present study, we generated a two dimensional stimulus space of Glass patterns incorporating uncertainties of criterion-based or noise-based origins and tested the transfer of the learning effect between them. For the criterion-based dimension, intermediate spiral patterns were generated by morphing between radial (0 deg of spiral angle) and concentric (90 deg of spiral angle) patterns (Li, Mayhew, Kourtzi, 2009). For the noise-based dimension, different proportions of noise were embedded in radial and concentric patterns. We trained two groups of participants in four successive days on categorizing the Glass patterns along the criterion-based and the noise-based dimensions respectively, and tested on the uncertain stimuli of both dimensions before and after the training. Our psychophysics experiments showed that the learning effect can transfer from criterion-based dimension to noise-based dimension, but not vice versa. Especially, the transfer happened only when participants were aware of the two stimulus dimensions. Further fMRI experiment in which participants encountered both uncertainty dimensions showed that the two uncertainties activated dif-

ferent brain areas. That is, the criterion-based uncertainty induced more activation in ventral prefrontal cortex whereas noise-based uncertainty led to more activation in cingulate cortex. Altogether, the current results suggested that two separate but not independent neural networks are engaged in processing the different sources of uncertainty.

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26.503 Uncertainty representation of low-level visual attributes

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There is increasing behavioral evidence that humans represent uncertainty about sensory stimuli in a way that it is suitable for decision making and learning in a statistically optimal manner. Do such representations of uncertainty exist for low-level visual stimuli, and furthermore, are they probabilistic in nature? We tested whether subjective assessment of the orientation uncertainty of a stimulus consisting of a fixed number of Gabor wavelets of different orientations reflects the true distribution of orientation uncertainty of the stimulus. Textured gray-scale stimuli were created by superimposing Gabor wavelets of three spatial frequency bands with their orientation randomly sampled from a bimodal Gaussian distribution. After 2 seconds of stimulus presentation, two oriented lines were displayed and subjects were asked to indicate the overall orientation of the stimulus by choosing one of the lines, or to opt not to respond if they were uncertain about the orientation. The orientation of the two lines matched the mean orientation of the stimulus orientation distribution and one of the modes. On average, subjects strongly preferred the mode (65%) over the mean (20%) and only rarely chose not to respond (15%) when the distribution of the orientations had two prominent modes. Increasing the variance of each mode led to a gradual reversal of ratios between the “mode” and “uncertain” responses. When the increase of variances changed the shape of the distribution to unimodal, subjects chose the mode 25%, the mean 15%, and the “uncertain” option 60% of the time. Results suggest that uncertainty associated with low level visual stimuli is explicitly represented as a probability distribution at a level of precision that goes beyond that of a simple parametric representation.

26.504 Internal uncertainty, rather than expected performance, determines visual confidence

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Visual confidence refers to the observer's ability to predict her performance level in a visual task. High confidence judgments can result from low stimulus uncertainty or high predicted performance. While uncertainty and performance are usually inversely related, we provide here a method to decouple this relationship, and determine whether confidence is better accounted for by our ability to estimate our own level of uncertainty or by our ability to correctly predict our perception. In order to decouple uncertainty and performance, we used the fact that internal uncertainty (represented by the spread of the posterior distribution in Bayesian models) is determined both by sensory uncertainty (the likelihood) and expected uncertainty (the prior). Therefore, different levels of internal uncertainties can be achieved by manipulating the prior expectation. Observers were placed in a dual task on motion direction perception (Barthelmé & Mamassian, 2010, PNAS). In the first task, they chose one out of two noisy random-dot kinematograms (the one moving upwards or the one moving downwards) as the one they were more confident that it would maximise their performance in the second task. In the second task, they discriminated whether the mean direction of the chosen kinematogram was slightly to the left or the right of the vertical. Unknown to the observers, the mean direction of the downward stimulus was sampled from a more focused distribution (high prior) than the upward stimulus. This manipulation led to less internal uncertainty for stimuli moving downwards, but at the same time worse expected performance for these stimuli (the reverse is true for stimuli moving upwards). Observers chose significantly more often the stimuli moving downwards

in the choice task when the choice was between two stimuli with identical physical uncertainty. In conclusion, internal uncertainty, rather than expected performance, determined visual confidence.

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26.505 Ventral lateral prefrontal areas reflect an influence of past experiences of weak signals on perceptual decision making

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Perceptual decision making is regarded as a process to integrate sensory signals toward appropriate action. Perceptual decision is made more quickly and more precisely with increasing the strength of signals and this tendency is reflected by the dorsal lateral prefrontal and intraparietal areas (Kim and Shadlen, 1999). At the same time, perceptual decision is also made by statistical knowledge of past experience (Carpenter and Williams 1995; Shadlen, Britten et al. 1996; Rome, Brody et al. 1999; Gold and Shadlen 2007). Does signal from statistical knowledge determine perceptual decision making similarly to current sensory signals? If so, statistical knowledge based on stronger signal should more greatly influence perceptual decision making. Last year, we showed that a past-experienced very weak signal more greatly influences decision making than stronger signals (Nishina, Kim, Watanabe, VSS, 2010). Here, we conducted fMRI experiments to examine the underlying mechanism for this puzzling behavioral finding. Using a multivoxel pattern analysis (MVPA) originally developed by Kamitani and Tong (2005), we found that the behavioral results were significantly highly correlated to the decoded performance based on fMRI signals in ventral prefrontal areas but not to that in dorsal lateral prefrontal or intraparietal areas. These results indicate that ventral lateral prefrontal areas reflect an influence of past experiences of weak signals on decision masking.

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26.506 A strong interactive link between sensory discrimination and intelligence

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The general goals of perception are (1) expedient processing of relevant information and (2) suppression of irrelevant information. These same goals are also central to cognitive processes, including general intelligence (Galton, 1883). The existence of this general constraint for efficient information processing might indicate the existence of common ‘processes’ that underlie both general intelligence and sensory discriminations (Cattell, 1886), predicting links between perceptual performance and abilities associated with intelligence.

We addressed this question by measuring duration thresholds for motion direction discriminations of stimuli varying in size. The typical (group-level) result is a considerable increase in thresholds with increasing stimulus size – a finding taken to indicate spatial suppression of large, background-like motions (Tadin et al., 2003). We utilized duration thresholds because they are effectively a measure of how quickly the visual system accumulates task-relevant stimulus information (Gold & Shadlen, 2000). This, in turn, suggests that lower duration thresholds may correlate with higher IQ. However, as higher thresholds for large stimuli indicate effective spatial suppression, higher IQ may correlate with stronger spatial suppression. Our results confirmed this interactive link between IQ and sensory discriminations. Specifically, high IQ subjects were better-than-normal at perceiving motion of small stimuli, but worse-than-normal at discriminating motion of large stimuli – i.e., exhibiting stronger-than-normal spatial suppression. The correlation between IQ and suppression strength was 0.66 ($p=0.02$), which is notable given typical test-retest reliability of IQ measurement.

Evidently, a robust correlational link exists between efficient processing of sensory information and intelligence. These results are, to the best of our knowledge, the strongest link between IQ and perceptual discriminations (links with traditional inspection time measurements rarely exceed 0.3). One possibility is that utilization of duration threshold measurements as an index of perceptual information accumulation speed provides a more accurate glimpse into the processes shared by sensory and cognitive systems.

26.507 Action selection requires predicting future uncertainty

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Action selection based on predictive models involves look-ahead to estimate the likely outcome of an action sequence. However, prediction uncertainty grows with both the complexity of the model generating estimates and the length of look ahead. Thus, if humans utilize knowledge of the uncertainty associated with their estimates, changes in their response strategies should be observed as a function of the model complexity and predictive horizon imposed by different tasks. To test this hypothesis, we examined human performance in a predictive decision making task. Observers launched "arrows" toward targets in a computer display. They could adjust the arrow's position during its trajectory, and when they were certain the arrow was on target, they pressed the spacebar to relinquish control. Points were awarded as a function of the arrow's distance from the target when control was relinquished (missing the target resulted in zero points). Observers launched three arrow types in random blocks (identified by color) with dynamics models of increasing complexity (constant velocity, constant acceleration, constant jerk). The proper solution to this problem is to compute an expected value at each point in time and relinquish control when the expected value is at a maximum, which necessarily takes into account uncertainty. Observers' actual uncertainty was measured in interleaved blocks of trials in which the arrow's trajectory endpoint had to be extrapolated from a set trajectory. Behavior was consistent with the predictions of a model-based observer. Predictive uncertainty increased as a function of distance from the target and model-complexity as reflected in the timing of observers' relinquish control decisions, which were farther along the trajectory for the constant jerk model than constant acceleration than constant velocity. These results provide direct evidence that human observers do incorporate knowledge of uncertainty of look ahead when making decisions.

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26.508 Overcoming uncertainty aversion with visual lotteries.

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Uncertainty aversion is a preference for gambles with known risks over gambles with unknown risks (uncertainty). In a typical Ellsberg paradox experiment (Ellsberg, 1961), people prefer to bet on an urn with 50 green and 50 red marbles than on one with 100 marbles in which it is unknown how many of them are green and how many are red. We created two sequential search tasks, one abstract and one visual, whose outcomes are exactly the same as a lottery with, for example, a 70% probability of winning \$10 and a 30% of winning nothing. In the abstract search, subjects saw a 10x10 grid of boxes and knew that 7 of them contained a green chip. They could open 10 boxes and finding at least one green chip would make them win \$10. In the visual search, subjects had to look for Ts among Ls on a 1/f noisy background and were awarded \$10 for correct answers. Half of the screens would contain one T, but the probability was unknown to subjects. By varying the opacity of the objects, it was possible to manipulate visual uncertainty and match, for every subject, the probability of a correct answer with the 70% probability of finding a green chip. Therefore, the abstract search was equivalent to a lottery with known probabilities (risk) and the visual search to one with unknown probabilities (uncertainty). While our subjects exhibited uncertainty aversion in the Ellsberg's paradigm, they did not prefer the abstract risky lottery to the visual uncertain lottery. Perceptual tasks have already been proven to produce nearly-optimal performance, as opposed to abstract lotteries in which people are consistently suboptimal (Maloney et al, 2006; Navalpakkam et al, 2009; Pedersini et al, 2010). Our results suggest that visual lotteries also contribute to eliminate cognitive biases like uncertainty aversion.

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Motion: Neural mechanisms

Saturday, May 7, 2:45 - 6:30 pm

Vista Ballroom, Poster Boards 509 - 520

26.509 The motion after-effect in the optomotor response of zebrafish

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The motion after-effect (MAE) in human perception has been studied because it gives us good insights for understanding motion processing in the visual system. Visual function of Zebrafish (*Danio rerio*), which is a simple model vertebrate amenable to genetics, has been studied using optokinetic response or optomotor response. In this study, we demonstrate the existence of MAE in the optomotor response of zebrafish. Vertical square-wave drifting gratings were presented to freely swimming adult zebrafish as adaptation stimuli. A circular transparent fish tank (9.5 cm in diameter) was surrounded by computer monitors for stimulus presentation. A non-transparent column (4 cm in diameter) was also placed in the center of the fish tank for monocular stimulus presentation. During presentation of drifting gratings at a constant velocity (300 deg/s), zebrafish intermittently pursued the drifting gratings. We changed spatial frequency of gratings and identified the frequency band which stably elicited this optomotor response (OMR) in zebrafish. Then, applying the most appropriate spatial frequency for eliciting OMR as the stimulus parameter, we investigated behaviors of zebrafish after presentation of drifting gratings. Just after cessation of stimulus movement (stimulus was changed into uniform gray background), zebrafish showed turning response as if the stimulus were moving in the opposite direction. This phenomenon indicates that adaptation of motion stimuli elicited MAE in OMR of zebrafish. In addition, as the duration of adaptation period increased, the behavioral response delay became shorter. Combining physiological studies and this experimental system might contribute to clarify not only neural mechanisms of MAE, but also general computation manner of motion direction in the visual system.

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26.510 An augmented Barlow-Levick model detects onsets and offsets of motion

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Freezing is an effective defense mechanism for some prey because many animals rely on visual motion to distinguish objects from their surroundings. Kinetic boundaries, defined as discontinuities in the optic flow field, are constantly produced by motion parallax during egomotion as well as by kinetic occlusion during object motion, even under conditions of perfect static camouflage. Perceiving a kinetic boundary, the foundation of motion-based figure-ground segregation, requires the detection of an unexpected onset or offset of otherwise constantly moving contrast patches. Many cells in primate V1 are directionally selective for moving contrasts, and recent reports suggest that this selectivity arises through inhibition of contrast signals moving in the cell's null direction, as in the rabbit retina. The Barlow-Levick motion detection circuit is extended in this work to also detect motion onsets and offsets by reapplying its mechanism to the output of directionally selective cells. The selectivity of this circuit, measured as its peak response to motion onset/offset compared to its peak response to constant motion, is analyzed as a function of stimulus speed. Because of the temporal ordering of excitation and inhibition that model onset and offset cells receive, offset cell speed tuning is biased towards higher speeds than onset cell tuning, similarly to MT cell speed tuning when exposed to speed ramps (Schlack et al., 2007, *J Neurosci* 27(41):11009-11018). In the context of a population of neurons with different preferred speeds, this asymmetry addresses a behavioral paradox — why subjects in a simple reaction time task respond more slowly to motion offsets than onsets for low speeds (Kreegipuu & Allik, 2007, *Psych Res* 71(6):703-708), even though neuronal firing rates react more quickly to the offset of a preferred stimulus than to its onset (Bair et al., 2002, *J Neurosci* 22(8):3189-3205).

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26.511 Temporal integration and interaction in the mechanisms underlying orientation- and direction-specific VEP

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Cortical responses arising from orientation- and direction-selective neurons can be isolated using stimuli in which orientation reversals (OR) or direction reversals (DR) are embedded in a sequence of 'jitter' events (Braddick et al, Nature, 1986; Wattam-Bell, Vision Res, 1991), providing a tool to study cortical function in normal and atypical development.

We examined how the OR and DR responses are affected by the frequency of these jitter events. OR or DR events were presented at 3.125 or 6.25 reversals/sec, with the interleaved jitter events at 12.5, 25, 50 or 100 jitter/sec (100 Hz frame rate). For OR, the orientation-specific signal/noise ratio (snr) declined steadily with jitter frequency. snr was a function of absolute jitter frequency, rather than the ratio of jitter to reversal rate. DR showed a quite different pattern of results: for 3 direction reversal/sec, snr was largely independent of jitter rate, while for 6 reversal/sec, snr increased with increasing jitter frequency.

We conclude that the two forms of cortical selectivity show quite different temporal properties: (1) OR responses depend on integrating the contrast pattern providing orientation information over a longer period than the equivalent for DR; (2) OR shows no evidence of interaction between the jitter events and orientation reversals; (3) in contrast, DR shows a strong interaction between the timing of reversal and jitter events; but (4) DR requires only the minimum two frames required to define directional motion and is not enhanced by integrating information from more than 2 frames. As well as characterising cortical dynamics, these results help to select the optimal timing parameters for OR- and DR-VEP when investigating cortical selectivity in infants and adults, including the effects of prematurity and early brain damage.

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26.512 Retinal and cortical effects of transcranial electric stimulation

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Transcranial electric current stimulation (tES) of the human brain is assumed to affect cortical excitability by invoking subthreshold modulation of neuronal activity. This assumption has been used to interpret clinical studies where tES improved stroke recovery, alleviated chronic pain, or treated depression. Our goal is to understand how electrical stimulation leads to changes in brain and behavior. A recent study has shown that application of transcranial alternating current stimulation (tACS) over the visual cortex induces the perception of flashes of light (phosphenes). The claim that these phosphenes were generated cortically has led to considerable debate. We applied tACS over visual cortex with a reference electrode on the vertex; and measured current thresholds for the detection of phosphenes with a Bayesian adaptive method. Then, we shifted the stimulating electrode over to the temporal lobe; away from visual cortex and towards the retina. This simple manipulation enhanced the efficacy of the stimulation as measured by lower current thresholds. This suggests that stimulation of the retina plays a significant part in the generation of phosphenes by tACS. To investigate whether tES induces behavioral changes that are likely caused by direct cortical stimulation, we investigated whether tES could change motion adaptation. We used a standard 40s adaptation design with 4s top-ups, coherent random dots as the adapting stimulus, and dots with varying coherence to measure the strength of the MAE. Preliminary results show that the strength of motion adaptation was reduced by simultaneous stimulation with an alternating current of 1mA at 10Hz over human MT+. Many mechanisms could underlie this effect. But, if tES affected both active (adapting) and inactive (not adapting) cells equally, one would not expect any influence on the MAE. Therefore, our finding suggests that tES could be targeted at cortical neuronal populations in an activity dependent manner.

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26.513 Intermittent motion stimuli stabilize neuronal responses in area MT: Implications for the perceptual stabilization of visual ambiguities

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When ambiguous stimuli are intermittently presented, the prevalence of perceptual alternations depends on the duration of the intermittent blank interval. Short interruptions (<0.5 s) cause perceptual alternations, whereas long interruptions (> 1.0 s) stabilize perception into long sequences of one dominant interpretation. Here we show how response characteristics of sensory neurons in macaque area MT are influenced by the interruption duration during the intermittent presentation of three different motion stimuli: 1) ambiguous structure-from-motion, 2) unambiguous motion, 3) dynamic random noise. For all stimulus types, spike rate variability decreased when interruption durations were systematically increased from 250 to 2,000 ms. Activity fluctuations between subsequent trials and Fano Factors over full response sequences were both lower with longer interruptions, while spike-timing patterns became more regular. These changes were independent of general adaptation effects and accompanied by increases of spectral power in the high Gamma range of the local field potential, suggesting an increased involvement of the local cortical network. In general, such a network-driven neuronal response stabilization with repeated stimuli may increase the signal-to-noise-ratio of the neural code and allow a more efficient information transfer among neurons. In the particular case of ambiguous stimuli, where perception may depend on small fluctuations in neural activity, a blank interval dependent reduction of response variability could be a crucial determinant of the perceptual stabilization of intermittently presented visual ambiguities.

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26.514 Image velocity coding in the primate visual system: A possible role for MT component neurons

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Neurons in the Middle Temporal (MT/V5) area of the primate brain have been classified into Component (C) and Pattern (P) types (Movshon et al., 1983; Albright, J. Neurophysiol., 1984). The rationale for the existence of P types is well established and the common thinking is that they integrate multiple motion directions over a patch of the retina and respond to the overall pattern motion, not to the motion of individual components making up the pattern. The function/role of neurons that respond primarily to the components (C-type) is less well understood. While developing a velocity code based on the outputs from small sets of MT pattern neurons (Perrone & Krauzlis, VSS, 2007) we have discovered an important function that could be filled by MT component neurons. MT neurons are speed tuned only and so the determination of image velocity relies on the combination of outputs from a set of neurons tuned to a range of image speeds and consequently with different receptive field sizes. Component neurons can be used to prevent the velocity estimates being dominated/skewed by the outputs from MT pattern neurons with the largest receptive fields. In our velocity code we use C units to introduce a spatial derivative mechanism; we propose that each MT pattern neuron is inhibited by spatially adjacent MT component neurons tuned to the same speed. The amount of inhibition is made dependent upon the contrast of the stimulus by exploiting the fact that some MT neurons change their speed tuning at low contrast (Krekelberg et al., J. Neurosci., 2006). The resulting mechanism enables good spatial localisation of the moving image feature at high contrast but allows for greater pooling and spatial integration at low contrast, consistent with MT surround inhibitory effects (Pack et al., J. Neurophysiol. 2005).

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26.515 Multivariate classification of motion direction using high-field fMRI.

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Previous studies have demonstrated that the perceived direction of motion of a visual stimulus can be decoded from the pattern of fMRI responses in occipital cortex (Kamitani and Tong, 2006). One possible mechanism for this is a difference in the sampling of direction selective columns between voxels, implying that sub-voxel information may be accessible with fMRI. To assess the possible sources of this direction-selectivity, we tested how classification accuracy varied across different visual areas and subsets of voxels for 8-way direction classification. Functional imaging data were collected using 3D-gradient-echo EPI at 7T (Achieva, Philips; SPMMR Centre, Nottingham) using 1.5mm isotropic voxels, (volume TR 2s). In one set of analyses we tested how classification accuracy varied with the number of voxels used. We used a 'searchlight' technique that performs classification based on a spherically defined subsets of voxels (Kriegeskorte et al, 2006) and found classification performance above chance across several visual areas (V1-V4, V5/hMT+) and in areas of the intraparietal sulcus, with a range of searchlight sizes (radius 7.5-10.5 mm). In the second set of analyses, we looked at classification performance after combining data across different voxels within visual areas (with similar visual angle preference from retinotopy) before classifier training. Preserved classification accuracy when averaging in this way, compared to random averaging of voxels, suggests that there may be large-scale biases at the level of retinotopic maps underlying some part of our results (see also Freeman et al, 2010).

26.516 Decoding perceptual choices for motion stimuli of varying coherence

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Most models of perceptual decision making assume that sensory evidence is accumulated until a decision threshold is reached, even when this evidence is dominated by noise. One important question is whether the brain performs the same or different computations to produce choices under high and low visibility. Here we specifically investigated how the strength of sensory evidence influences how perceptual choices are made in the human brain. Subjects were required to judge the direction of motion of dynamic random dot patterns of varying motion coherence while their brain activity was measured with fMRI. We used multivoxel pattern analysis to decode choices from local patterns of brain activity under different coherence levels. We found a positive relationship between motion coherence and decoding accuracy for perceptual choices in early visual cortex, suggesting that stimulus representations increasingly contribute to perceptual choice with increasing sensory evidence. Interestingly, we also found a negative relationship in posterior parietal brain regions, with highest decoding accuracies for low levels of motion coherence. This could indicate that different mechanisms contribute to perceptual choices for motion under high and low sensory evidence. These results are discussed in light of current models and previous experimental results on the neural underpinnings of perceptual decision making.

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26.517 Illusory centrifugal motion direction observed in stationary stimuli: dependency on duration and eccentricity

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All stationary stimuli of fixed duration have motion energy. Specifically, the net motion direction in such stimuli is zero and the amount of motion energy increases with decreasing duration. Consequently, brief stationary stimuli will stimulate cortical motion detectors, and might lead to perception of illusory motion direction if the readout mechanisms are unbal-

anced. One such unbalancing is the centrifugal directional anisotropy in area MT, where preferred directions of neurons with peripheral receptive fields tend to be oriented away from fovea (Albright, 1989). Theoretically, this centrifugal bias might generate illusory motion direction in stationary visual stimuli. Given the broadening of motion energy in brief stimuli, such effect should increase as the stimulus duration decreases. Here, we tested this hypothesis by presenting stationary vertical gratings (0.5c/deg, raised cosine spatial envelope, radius = 5deg, 98% contrast) at 5 eccentricities along the horizontal meridian (0, 20, 40, 60, 80deg). Stimuli were presented in a temporal Gaussian envelope with durations ranging between 5 and 500ms. Observers' task was to identify perceived motion direction (guessing when unsure). No feedback was provided. Results showed that as the stimulus duration decreased and as eccentricity increased, observers tended to perceive consistent motion direction in these stationary stimuli. Specifically, as predicted, the observers were biased to perceive these stimuli as moving away from fovea. We also found "baseline" biases among observers for foveally presented stimuli. In a separate experiment, we quantified these results using a velocity nulling procedure. In summary, briefly presented stationary stimuli are perceived as moving in centrifugal direction when presented in visual periphery. One possible explanation for this illusion is that these stimuli, by virtue of their broad temporal frequency spectrum, stimulate centrifugally biased motion mechanisms in area MT.

26.518 Resolving the projection of a moving stimulus on the human cortical surface

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Introduction. Optical imaging techniques have demonstrated that the cortical response to a moving visual stimulus appears to have an anticipatory leading edge component to the representation (Jancke et al, 2004). We sought to temporally and spatially resolve a moving stimulus on the cortical surface in humans using functional magnetic resonance imaging (fMRI). While the hemodynamic signal is sluggish, its response characteristics are highly reliable, and the ultimate resolving power is an issue of signal and noise. Our experimental goal was to determine the limits of the fMRI technique to resolve the path of a moving stimulus in the retinotopic human visual cortex.

Methods. Subjects' brains were scanned with a 3 T MRI scanner and a 32-channel head coil. Standard retinotopic mapping and cortical flattening procedures were performed. We experimented with EPI sequences with different k-space trajectories as well as reconstruction techniques to optimize the spatial and temporal resolution limits. The stimulus was a high contrast flickering checkerboard with a circular aperture that moved through the visual field with a constant velocity in polar angle at a fixed eccentricity.

Results. For each stimulus velocity, we were able to determine the amount of data required to achieve the same precision in the estimation of spatio-temporal position. We noted asymmetries between the leading and trailing edges, as a function of velocity.

Conclusions. We have demonstrated the limits of resolving moving stimuli along the human cortical surface. Being able to image the complete cortical representation of an object's trajectory allows us to test a number of hypotheses in areas of visual perception, including attentional object tracking and the properties of objects as the disappear behind occluders.

26.519 Visual trails : when perceptual continuity breaks down

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"Visual trailing" is a transient but dramatic disturbance of visual motion perception of unknown origin: the subject perceives a series of discrete stationary images trailing in the wake of otherwise normally moving objects. Although this phenomenon is most frequently encountered after ingestion of prescription and/or illicit drugs (i.e. Lysergic Acid Diethylamid or LSD), it has also occasionally been reported following brain damage or neurological disorders. Visual trails, because of their discrete and repetitive nature, may represent the perceptual manifestation of an underlying periodic neural process. This periodicity could arise outside of the visual system altogether (e.g. eye movements, motor tremor), or may be the result of faulty motion computation mechanisms (e.g. motion smear suppres-

sion), or finally, may point to a more general oscillatory process that affects, among other things, the motion perception system. However, only qualitative case reports exist in the literature, and a quantitative account of visual trails is currently lacking. We report our attempt to collect both qualitative and quantitative data on this phenomenon by means of an online survey. We simulated visual trails in a short movie and varied the interval between successive persisting images of moving objects (10 intervals between 25 and 250 ms); then we instructed past users of LSD (as assessed via a questionnaire) to report which sequence best corresponded to their experience of visual trails. Although the survey is still ongoing, we present results from more than 200 responses. Participants consistently selected a time interval between images of 60ms on average, corresponding to an underlying periodicity in the 15-20Hz (beta) range. This is but a preliminary step, and we suggest key experiments that should help identify the oscillatory underpinnings of this rare disturbance, and eventually lead to important insights into how our brains update conscious visual perception in time.

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26.520 **The critical speed for motion streak processing in early visual cortex**

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A fast-moving object is perceived as a streak because of the temporal integrating of the visual system. The explanation of motion streaks in terms of linear filtering process provides support for the observation of cortical response maps under extreme motion velocities. The cortical domains with orientation preference perpendicular to the motion direction are preferentially activated when the dots are moving at low velocities, while those with orientation preference parallel to the motion direction are preferentially activated when the dots are moving at high velocities. However, it is still unclear how stimulus velocity may influence the cortical population activities and to what extent the ensemble spatiotemporal preferences determine this reversal process. Here we used intrinsic optical imaging method to systematically measure the cortical orientation response in cat areas 17 and 18 to drifting dots at different velocities. For both areas, beyond a critical velocity, the cortical activity reversed to patterns with orthogonal orientation preference. We find that the critical reversal velocity is roughly three times higher for area 18 relative to area 17. Our results demonstrated an interesting phenomenon: for an intermediate range of velocities, the evoked cortical activity patterns are reversed between areas 17 and 18. The difference in the reversal speed can arise from the linear feed-forward processing and the spatiotemporal filtering properties of neurons in both visual areas. We suggest that such a co-operation of areas 17 and 18 can explain the psychophysical observation that the perceived critical speed increase with the size of the moving dots. Our perception is therefore a pooling of distributed activities across multiple cortical areas.

Spatial vision: Mechanisms

Saturday, May 7, 2:45 - 6:30 pm

Vista Ballroom, Poster Boards 521 - 535

26.521 **The Psychometric Function: Why we should not, and need not, estimate the lapse rate.**

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In their influential paper, Wichmann and Hill (2001, *Perception & Psychophysics*, 63,1293-1313) have shown that the threshold and slope estimates of a psychometric function may be severely biased when we assume that the lapse rate equals 0 but lapses do, in fact, occur. Wichmann and Hill also claim that threshold and slope estimates are essentially unbiased when we allow the lapse rate to vary within a rectangular Bayesian prior during the fitting procedure. Here I fail to replicate Wichmann and Hill's results. Instead, I show that both threshold and slope estimates are biased when we follow Wichmann and Hill's suggestion to estimate the lapse rate. I explain the mechanism behind the bias in detail. Fortunately, since we are rarely interested in the absolute value of a threshold or slope, bias in the estimates thereof need not necessarily be a problem. Instead, we are generally concerned with whether differences among parameter values exist between experimental conditions. I demonstrate that, unlike estimates of the absolute value of thresholds, estimates of differences between thresholds val-

ues obtained in different conditions are unbiased even if an assumed, fixed lapse rate does not match the true, generating lapse rate. Similarly, results of statistical model comparisons are virtually unaffected by a mismatch between an assumed, fixed lapse rate and the generating lapse rate. In contrast, severe negative consequences for statistical model comparisons can be obtained when we allow the lapse rates to vary during fitting. I explain the mechanism behind these negative consequences in detail. Overall, my results indicate that unless we are interested in the absolute values of the parameters of a psychometric function, we should not, and need not, estimate the lapse rate.

26.522 **The interaction between flanker phase and position in lateral masking**

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The visibility of a target stimulus can be affected by the presence of other stimuli (flankers) projected onto different parts of the retina. Previous studies showed that the greatest lateral facilitation effect occurs when the flanker has the same orientation, phase as the target and at the collinear position. Here, we show that there is an interaction between the flanker phase and position in lateral interaction. The task of our three observers was to detect a 4 cy/deg vertical Gabor target in the presence of vertical flanker Gabors. The target was in sine phase related to the fixation. The flankers had either the same or the opposite phase from the flanker. Flanker locations were either 0 (collinear), or 90 deg (side) away from the collinear axis. The distance between the flankers and the target varied from 1 to 7.5 wavelengths. The flanker contrast was 50%. We measured target thresholds with a 2AFC paradigm and a PSI staircase method at 75% correct response level. Compared with the no-flanker condition, the collinear flankers significantly decreased target threshold only if the flanker was in the same phase as the target. The collinear opposite phase flanker showed little, if any, effect. The opposite phase side flanker significantly decreased target threshold while the same phase side flanker did not. That is, the phase effect for the collinear flanker was opposite from that of the side flankers. The side flanker has an effect only if the bright region of the target links to the bright region of the flanker, and the dark region to the dark. This result may be consistent with the notion of the border ownership in which facilitation occurs when the target and the flankers signal the two opposite border of the same surface.

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26.523 **Spatial frequency bandwidth of surround suppression**

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The ability to detect a target situated in the visual periphery is impaired if a stimulus with similar physical characteristics is located surrounding the target. In particular, the contrast detection threshold of a grating located in the periphery is increased if a surrounding grating of the same frequency and orientation is present. This inhibition between center and surround has been termed surround suppression. We measured the spatial frequency bandwidth of surround suppression in the periphery for different spatial frequencies (0.5, 1, 1.3 and 5cpd) of a sinusoidal grating (target) surrounded by a grating with different spatial frequencies (surround). Using a Bayesian adaptive staircase we have measured contrast detection thresholds in an 8AFC detection task where the target (grating with 2.3deg-Butterworth window) could appear in one of eight possible positions at 4deg eccentricity. The target appeared on top of a surround grating (grating with 9deg-Butterworth window) with the same or orthogonal orientation. In each session we fixed the spatial frequency of the target and changed the spatial frequency and the orientation of the surround. When the surround is orthogonal to the target, the thresholds are similar to those obtained without surround and independent of the surrounding spatial frequency. However, when the target and surround had the same spatial frequency and orientation, a strong suppression was obtained. When the spatial frequency of the surround differed from that of the center, the suppression rapidly reduced, with detection thresholds decreasing as a Gaussian function of the spatial frequency difference. The bandwidth in octaves of the Gaussian function fitted to the detection thresholds was around 4 for a target frequency of 0.5cpd, and

decreased with the increasing target spatial frequency to around 1 at 5cpd. We suggest that this result could be a consequence of the decreasing bandwidth of the simple cells present in the striate cortex.

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26.524 Bandwidths of gain control pools in overlaid and center-surround masking

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Overlaid sinusoidal gratings which differ greatly from a target grating in spatial frequency or orientation can create a large performance drop in certain suprathreshold hyperacuity discrimination tasks. This between-channel masking has been attributed to pooled gain control processes. A similar masking effect is found when targets and masks are of the same spatial frequency and orientation, but spatially displaced (center-surround masking). These effects have also been attributed to pooled gain control processes. In the current experiments, we measure bandwidths of the putative gain-control pools with overlaid and center-surround stimuli. The target was always a vertical 4 cpd grating. Stimulus configurations and discrimination tasks were designed to isolate masking interactions previously found in the overlaid case: 1) orientation discriminations with an overlaid vertical 16 cpd mask and 2) spatial frequency discriminations with an overlaid 4 cpd horizontal mask. In the first case, orientation bandwidths were measured by changing mask orientation from the vertical until interactions were no longer observed relative to an unmasked control. In the second case, spatial frequency bandwidths were measured. Orientation and spatial frequency bandwidth measurements were then repeated in comparable experiments with center-surround stimuli. On both the orientation and spatial frequency dimensions, bandwidths measured with overlaid components were considerably broader than those measured with spatially displaced masks. To the extent that our masking results actually reflect characteristics of contrast gain control pools, these differences may indicate different pooling processes entirely, or the same process but with a more limited pool in the center-surround case. Finally, we note that an illusory contour separating center and surround becomes increasingly visible as target and mask differ. It is known that a real gap of just a few pixels between center and surround stops masking effects. We speculate that an illusory contour might also be able to restrict the masking effects.

26.525 Efficient integration across spatial frequencies reflected in early visual areas

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Objects in a scene are composed of different spatial frequencies, and the combination of these spatial frequency components provides information about form. To perceive form, the visual system must efficiently integrate across spatial frequencies. While a number of studies have shown that integration across spatial frequencies is suboptimal for grating detection, Nandy and Tjan (2007) found it to be optimal for letter identification in both the fovea and periphery. How and at what stage of visual processing optimal integration across spatial frequencies occurs is unknown.

We used fMRI multi-voxel pattern analysis to investigate spatial frequency integration in the visual cortex. From the early visual areas (V1-V3), we measured BOLD response evoked by bandpass filtered letters X and O presented in the periphery, while subjects were engaged in a demanding task at fixation. The center frequencies for the octave-wide bandpass filtered letters were separated by two octaves, yielding a high and a low spatial frequency condition. A third composite condition was obtained by summing these two spatial frequency components. Using a linear support vector machine, we measured the accuracy with which multi-voxel activity within each visual area could be used to predict the identity of the displayed letter. The sensitivity (d') of the decoder for discriminating X from O in the low, high, and composite conditions was determined.

We found that in V1 discrimination was no better for the composite letter than the one-octave component letters. However, in V2 sensitivity was highest for the composite, where squared d' for the composite was approximately the sum of the squares of the components' d 's. In V3, d' for the

composite was approximately the sum of the components' d 's. This result suggests that efficient integration across spatial frequencies, as seen by a linear decoder operating on BOLD signal, begins in V2.

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26.526 Time-Course of Anisotropic Masking at High and Low Spatial Frequencies

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When a pattern of broadband spatial content is viewed, the multiple spatial components in the pattern stimulate detecting-mechanisms that suppress each other. We've shown that this suppression is anisotropic, being relatively greater at horizontal and least at obliques (Essock et al., *VisRes* 2003; Essock et al., *JOV* 2009). This suppression leads to better thresholds and greater saliency of obliquely-oriented structure when viewed in the presence of broadband or natural-like structure. Thus this anisotropic suppression (the "horizontal effect") appears to "whiten" the neural response to typical scenes (Hansen and Essock, *JOV* 2004; Essock et al., *JOV* 2009). We have measured the timing of this anisotropic suppression by varying the stimulus onset asynchrony (SOA) between a brief (50ms) test pulse of a (spatial) Gabor and the spatial mask (50ms pulse of 1/f broadband noise pattern) for different test orientations (Essock et al., *JOV* 2009). With an 8 cpd test, masking is greatest at 0ms SOA and with backward more effective than forward masking. Modeling of the temporal properties of the masking suggested that at least two suppression parameters underlie the performance anisotropies: a fast horizontal vs vertical bias, and a slow cardinal vs oblique bias. Here, we evaluated the time course of anisotropic broadband masking with test spatial frequencies of 2, 8, and 12cpd to assess the suppression anisotropies at different speeds. Results show strongest suppression at horizontal at all three test spatial frequencies, however, the time-course of the anisotropic suppression differs. Suppression is maximal at the 0ms SOA, but at the low spatial frequency, suppression is brief with little temporal asymmetry. That is, for transient, "high-speed" conditions (Meesse and Holmes, *ProcRoySoc* 2007; Essock et al., *JOV* 2009) the anisotropic suppression follows a different time-course than at the relatively sustained "low-speed" conditions.

26.527 The effect of mask contrast on spatiotemporal masking in younger and older subjects

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Although there is evidence for weaker centre-surround interactions in older subjects in tasks using dynamic stimuli (Betts et al., *Neuron*, 45(3), 361-6, 2005; Betts et al., *J Vis*, 9(1):25, 1-15, 2009), the effect of the surround is much stronger for older adults in tests of perceived contrast (Karas et al., *J Vis*, 9(5):11, 1-9, 2009). Previously, we measured detection thresholds for a horizontal 3.5 cycles-per-degree Gabor target masked by a small central sine wave mask, a surround sine wave annulus, and a combination mask (centre-plus-surround) of the same spatial frequency. Target onset, relative to the 40% contrast mask, varied across conditions. The shapes of the overlay masking functions obtained from younger and older subjects were similar to those found for young subjects by Saarela and Herzog (*J Vis*, 8(3):23, 1-10, 2008), but the overall level of masking was lower in older subjects. One potential explanation for this age difference is older subjects had lower contrast sensitivity for the mask. The current experiment tests this hypothesis by measuring masking functions with different mask contrasts ranging from 10% to 80%. We found that varying contrast had different effects on masking in younger and older subjects, and that the age difference could not be explained by a difference in contrast sensitivity. Our results suggest that the relative strength of age-related changes in centre-surround interactions depend on the spatiotemporal properties of the stimulus.

26.528 Alignment judgements: Greater precision within than between cortical maps

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The visual cortex is hierarchically organised so that local features are processed in early areas with increasingly complex operations occurring with each subsequent level. Many of these early- to intermediate-stages are represented retinotopically (Wandell, Brewer, & Dougherty, 2005). Within the regions (i.e. V1) there are often populations of neurons which cluster together in terms of their tuning. When the system has to compare information from different populations of neurons (either those within a cortical region or those between regions) this may increase the chance of error affecting the precision of perceptual judgements. The current study investigated the precision of alignment discrimination between forms thought to be processed in separate retinotopic maps, as well as between forms thought to be processed by separate populations of neurons within a map. This precision was compared to that found when alignment judgements were made between forms processed in the same retinotopic map and processed by the same population of neurons, respectively. Our inter-map test used locally detected luminance-defined dots and the centres of radial frequency patterns (which require global processing) while the intra-map test used 'low' and 'high' spatial frequency Gabor patches. We found there was indeed extra positional error in conditions where an inter-map judgement had to be made. This error could not be accounted for by summing the positional error associated with each individual form within the stimulus set. However, extra error was not found when observers made an intra-map judgement. We conclude that a precision cost may be introduced to alignment judgements when position information is passed between - but not within - cortical regions.

26.529 Temporal characteristics of monoptic and dichoptic collinear lateral masking of contrast detection

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Purpose. Past studies using non-dichoptic viewing show that varying flank duration affects contrast detection threshold (CDT). We further investigated this effect by varying flank duration and the inter-stimulus interval (ISI) under monoptic and dichoptic viewing conditions. Methods. Four observers with normal vision participated. Target and both flanks were collinear, 3-cpd sinusoids, vertically oriented, separated center-to-center by 6-lambda (sigma=1.5 lambda). We normalized flank contrast (3X flank CDT) and used a forward masking paradigm: flanks and ISI were each presented at 67, 117, 250 and 500ms resulting in 11 (including simultaneous presentation) stimulus onset asynchronies (SOA) ranging from 0-1000ms. Target was presented to the dominant eye (250ms) and flanks to the dominant (monoptic) and non-dominant (dichoptic) eyes via mirror haploscope with septum. The task was 1-FC detection (yes/no) incorporating a 7-level MOCS. Each CDT was calculated via Weibull function from ≥ 700 trials. Results and Discussion. Simultaneous presentation produced CDT facilitation under monoptic (mean 19.0% \pm 3.86(SD)) and dichoptic (mean 10.1% \pm 2.46) viewing. SOA increase generally produced CDT increase. Monoptic mean facilitation ranged from 18.6% to 2.50% for the shortest and longest SOA, respectively. For the same SOA range, dichoptic viewing produced 11.8% facilitation to -8.31% (suppression). Best-fit functions to the relative CDT versus SOA results showed a simple, vertical shift downward for the dichoptic condition. This shift suggests similar mechanisms of contrast integration across space with additional gain reduction for the dichoptic mechanism. Analysis of the two SOA components showed that under monoptic viewing, longer flank duration tended to facilitate CDT more than longer ISI duration. Under dichoptic viewing these contributions to CDT appeared equal. Conclusion. Flank duration and ISI effects on contrast detection under dichoptic viewing appear consistent with current dichoptic, contrast discrimination (pedestal) models of contrast gain control.

26.530 Bisection and dissection of horizontal lines: the long and the short of the Oппel-Kundt illusion.

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Mamassian & Montalembert (2010) have proposed that there are two components to the vertical- horizontal illusion; the bisection of the horizontal line by the vertical contributing 16% and the anisotropy only 6%, making

the horizontal appear shorter by 22%. In contrast, in the Oппel-Kundt illusion a horizontal line divided by a regular series of vertical 'tick' marks appears longer than an unbroken line of the same length. Therefore, the aim of this study was to determine the conditions under which the size of a horizontal line is underestimated or overestimated depending on the presence of one or more vertical lines. We used the method of constant stimuli to generate psychometric functions from which PSEs were determined. We varied the size of the horizontal comparison line between 5.2-7.0 degrees and manipulated the number (0, 1, 5, and 9), the size (6.1/0.61 degrees) and the position (crossing/touching) of vertical lines on a horizontal line in a series of experiments. We also compared illusory percept when the divided and undivided segments were presented as a single stimulus to a condition where the two were presented separately. Results generated showed that the perceived length of a bisected horizontal line with a single central vertical tick is only decreased by 5-10% depending on the position and the size of the tick, whereas additional ticks increase the perceived size of the horizontal line by 5-6%. Additionally, we observed no illusory percept when the size of the vertical segment was equal to the size of the horizontal. Finally, we investigated the effects of asymmetrical bisection and monocular viewing on the vertical-horizontal and Oппel-Kundt illusions.

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26.531 When bigger is better

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One of the main factors of crowding is the spacing between target and flankers. The closer the flankers are to the target, the stronger is crowding. Recently, it was proposed that crowding strength is determined by the distance between target and flanker centroids (Levi & Carney, 2009). Here, we determined vernier offset discrimination in the periphery with different flanker configurations. When the vernier was flanked by two vertical lines, thresholds increased. Thresholds decreased compared to the two-lines condition when each of the lines was complemented to form a rectangle. This is in line with the centroid hypothesis because the rectangles' centroids are further away than the centroids of the single flankers. However, when crossing the upper and lower horizontal lines of the rectangles, performance deteriorated even though centroids are the same in this and the rectangle condition. These results can neither be explained by the spacing between the target and the flankers nor by centroid distance. Also simple pooling models fail to account for these results. We propose instead that grouping is a key factor in crowding: crowding decreases when target and flankers ungroup, crowding increases when target and flankers group.

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26.532 Jitter detection exceeds spatial frequency limit of the visual system

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The halftone screen with fine vertical gratings is often used to modulate image in the printing technology. When the halftone screen is disturbed by the jitter in horizontal direction we observe the lattice fringe (called banding) in the horizontal direction. Surprisingly, any frequency component does not exist in the spatial frequency domain of the banding. Also, the banding is detected even when the spatial frequency of the halftone screen exceeds the frequency limit of the visual sensitivity.

In this study we measured the spatial frequency properties of the halftone screen and the jitter in order to see the banding. The circular stimuli were of the vertical sinusoidal gratings with horizontal sinusoidal jitters which made on the paper with an ink-jet printer. The viewing distance was 2.5m. The stimulus size was 6.9degree of diameter. We varied the spatial frequency of gratings and jitters around the spatial resolution limit of the visual system as experimental parameters. The observer's task was to judge whether he saw the banding pattern in each stimulus with different jitter amplitude.

The results showed that the banding was observed for the jitter amplitude of lower than 10 arc-sec with spatial frequency of less than 60cpd. This means that the jitter amplitude threshold was in the level of hyper acuity. Also a banding pattern was observed even at the grating frequency of higher than the resolution limit.

These results suggest that a nonlinear process, e.g., adaptive sampling or nonlinear function, may exist somewhere between the photoreceptor mosaic and a higher level of the visual system to yield the banding pattern.

26.533 Reduced adaptation from complex grating on component grating is due to automatic interaction between components independent of attention

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In 1972, Tolhurst showed a reduced contrast threshold elevation of the 3rd harmonic component of a square-wave grating when observers adapted to the square-wave, as compared to adaptation to the 3rd harmonic by itself. This result can be explained either as an automatic mutual interaction between components in an early stage of visual processing, or as a top-down modulation that suppresses higher order components to maintain an integrated percept of the square wave at the fundamental frequency. The current study tested between these two possibilities, by examining whether extrinsic, top-down, attention is required to facilitate the interaction between components during adaptation leading to a reduced adaptive effect on the 3rd harmonic. We measured the contrast elevation of the 3rd harmonic grating (6 cpd) after adapting to a complex grating consisting of the 1st (2 cpd) + 3rd harmonic, compared to adaptation to the 3rd harmonic alone. Attention was manipulated by two tasks: the "attended" task required the observer to detect the sudden disappearance of the adaptor and the "unattended task" required observers to detect a target letters in a foveal RSVP stream. Our results showed a weaker adapting ability of the complex grating on its 3rd harmonic component in both attended and unattended conditions. Diverting attention attenuated the adaptation effect, and no interaction was found between attention and adaptors: attention affected the adaptation effect of both the complex grating and the single grating equally. These results suggest that the interaction between harmonics that weakens adaptation is an automatic process, likely occurring in early stages of visual processing.

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26.534 Ecological-optics origin of the style of European and East-Asian classical painting

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Despite the apparent universality of human vision, the style of classical paintings is remarkably different across cultures. Classical paintings in Europe after the renaissance typically consist of bright objects with strong shading on dark backgrounds, whereas those from north-east Asia (China, Korea, and Japan) tend to consist of motifs drawn in dark shades and contours on bright backgrounds. Notably, Asian paintings completely lack cast shadows and highlights, which are a central feature of the realism of European paintings. Image-statistics analysis shows that European paintings tend to have more contrast and skewness in most subbands compared to Asian paintings. I propose that these differences originate in part from differences in the structure of illumination in the two climatic regions. In the Mediterranean (e.g. Italy), illumination tends to be highly directional, and as a result the images of objects contain richly variegated shading and sharp highlights. In the Monsoon climate (e.g., South of Chang River) on the other hand, illumination is diffuse due to clouds and rain, and as a result shading is only found in the deepest concavities of objects, and highlights are blurred. It was found that under directional illumination objects have higher contrast and skewness than under diffuse illumination, consistent with the statistics of paintings. This suggests that in the two cultural regions, artists were first attempting to capture and emphasize the natural appearance of the environment.

26.535 Dioptic blur affects grating acuity more than letter acuity for contrast-modulated stimuli.

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It is valuable to consider the effects of blur, eccentricity and amblyopia on different measures of visual acuity, in particular grating and Snellen acuity (eg. Levi & Klein, 1982; McKee et al, 2003). For luminance stimuli, blur and amblyopia reduces grating acuity less than letter acuity. We examined the effects of dioptic blur on luminance, luminance-modulated (LM) and

contrast-modulated (CM) noise gratings and C letter acuity to gain further insight into the visual processing of CM stimuli. Modulation sensitivity functions for standard luminance, LM and CM Gabor patches (0.5-32 c/deg) were measured and cut-off spatial frequencies estimated. Luminance-modulated and contrast-modulated stimuli were created from background dynamic binary noise, which was unscaled (angular size of checks constant for all frequencies) or scaled (6 checks/cycle of modulator). Square C acuity was also determined. Modulation and acuity thresholds were measured using different levels of blur (0-4D) and a method of constant stimuli with 2AFC and 4AFC paradigms. Dioptic blur reduces modulation sensitivity to LM Gabors in a similar fashion to standard Gabors. CM modulation sensitivity is much lower, and the effect of blur is greater, particularly for unscaled noise. The effect of blur on C acuity though is similar for LM and CM stimuli, although the acuity threshold for CM stimuli is about 0.3 logMAR higher at all levels of blur. When comparing grating and letter (crowded or uncrowded) acuities for different levels of blur, whereas for LM stimuli the slope falls from 0.5 to 1.0, for CM stimuli, it can be more than 2.0. That is, blur affects grating acuity more than letter acuity for CM stimuli. This finding is new and suggests that different limits affect CM than LM detection. However letter acuities are similarly affected by blur, suggesting that once extracted, letter acuity is affected by a common limit. Acknowledgement: NA holds PhD Scholarship funded by the Government of Malaysia.

Spatial vision: Encoding and decoding

Saturday, May 7, 2:45 - 6:30 pm

Vista Ballroom, Poster Boards 536 - 551

26.536 Segmentation mechanisms are sensitive to and can segment by higher-order statistics in naturalistic textures

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Texture segmentation depends on the statistical properties of the textures in question, but which properties are biologically relevant remains unclear. Previously, we determined that contrast boundary segmentation in a single texture was affected by global phase structure - in particular, the texture density (VSS 2009). Here, we manipulate density and broadband phase alignment for boundaries between pairs of textures differing in orientation or phase alignment to uncover the statistical sensitivities of segmentation mechanisms. We created synthetic micropattern textures that mimic important statistical properties of natural textures (VSS 2009). We were able to remove all higher-order statistics by globally phase-scrambling the texture, or remove local phase alignments by phase-scrambling the micropatterns, while varying texture sparseness by changing the number of micropatterns. We created two types of texture boundaries using a quilting method: (1) orientation modulations, where one texture had vertical micropatterns and the other horizontal, and (2) phase alignment boundaries between different pairings of the intact, local (LS), and global (GS) scramble conditions. We obtained modulation-depth thresholds for all boundary types at a series of micropattern densities. Orientation-defined boundaries become easier to segment as density increases, with boundaries between GS textures being easier to segment than those between either intact or LS textures. As density increases, boundaries between GS and either intact or LS become more difficult, but boundaries between intact and LS textures become easier. We observe that boundaries defined by changes in phase alignment are no more difficult to segment than those defined by changes in orientation. These results lend support to the idea that sparseness is an important texture dimension impacting performance in segmentation tasks. Our findings suggest that early inputs to segmentation mechanisms are sensitive to higher-order statistics such as sparseness as well as simple attributes such as contrast and orientation.

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26.537 Spatial Frequency Weighting Functions for Perceived Contrast in Complex Imagery

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Perceived contrast of narrowband spatial patterns is directly relatable to contrast sensitivity and discrimination (Cannon & Fullenkamp 1991, 1995), but it is unknown whether band-limited contrast sensitivity can predict the perceived contrast of broadband, complex imagery like natural scenes.

On the other hand, the phenomenon of contrast constancy (Georgeson and Sullivan 1975) has been invoked to suggest that the visual system equalizes contrast responses across scale/spatial frequencies. To resolve this longstanding question, we measured perceived contrast weights across spatial frequency during viewing of photographic scenes. On each trial an image, a photograph of a real-world scene, is divided into two sets of eight 1-octave frequency bands, each of which has its amplitude varied by a random amount, and the two sets are reassembled into two test images. The observer chooses which of the two appears to have higher contrast, i.e. a larger range of grayscale values. Weighting functions can be derived as the correlation between trial-to-trial band weights and observer choice (chosen or rejected). We find that the weighting function peaks at mid-high spatial frequencies, with considerable variation between subjects, indicating that observers are not using a flat broadband contrast statistic (e.g. RMS contrast) to make their choices. Weighting function shapes are found to be dependent on image statistics including edge density and spatial frequency amplitude spectrum slope. Simulations equating perceived contrast with contrast response, incorporating predictions based on the effects of contrast gain control, produce similar results as the human observers.

26.538 Statistics of natural scene structures and material perception

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The human visual system is good at identifying the material composition of a surface using only the information contained within an image patch subtending that surface. Researchers have yet to design a computational model that approaches the performance of the human visual system in this task. We designed a new computational model and evaluated its performance using the Flickr Materials Database which contains 100 color photographs of surfaces from each of 10 material categories: Fabric, foliage, glass, leather, metal, paper, plastic, stone, water, and wood. We took several steps to develop this model. First, we performed Independent Component Analysis (ICA) at three different scales (simultaneously) and obtained a set of multi-scale ICA features. Second, we clustered these ICA features based on their scale, size, position, spatial frequency, orientation, and chromatic tuning. Third, we compiled a large set of natural material structures-concatenations of local multi-scale ICA features. Fourth, we examined the information content of each of these natural material structures for the 10 material categories and selected a set of natural material structures with high information content for each material category. Finally, we used the selected natural material structures to train a 10-category MoRPE probabilistic classifier. Our findings demonstrate that middle-level scene structures (i.e. natural material structures based on multi-scale ICA features) are a powerful source of information for solving this task.

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26.539 Orientation statistics of natural scenes: spatial-scale and temporal aspects

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There is evidence that the functional properties of the visual cortex as well as human behavioral performance are attuned to the statistics of the visual world (Karklin & Lewicki, 2009; Geisler et al., 2001). Within the orientation domain, pairs of oriented edges in natural scenes exhibit properties of smooth continuation (co-linearity and co-circularity) when examined at a fine spatial resolution (Sigman et al., 2001). However, in foveated visual systems, spatial resolution falls off precipitously with eccentricity. It is thus of interest to evaluate orientation statistics at the coarser resolution that applies in peripheral vision.

To examine this, we estimated pair-wise mutual information between oriented elements on the entire set of about 4200 natural images in the Van Hateren image database. We find the same pattern of smooth continuation at the finer spatial scales as in previous studies. However, for coarser spatial scales, we find significant violations of smooth continuation: with pairs instead exhibiting shared orientation that is insensitive to co-linearity, and little or no co-circularity. Examining the frequency of co-occurring oriented elements (adjacent pairs, triplets and so on) we find that the most frequently occurring patterns at the finer spatial scales are smoothly curved, whereas those at the coarser scales consist of iso-oriented repeated

patterns. These results suggest a vocabulary of shapes and patterns that neurons with coarser spatial coding (neurons with more eccentric receptive fields, and neurons in higher order visual areas) might be tuned to.

The second question we examined was how much of the information content was preserved across time in natural scene movies. Using a fine spatial scale, from a set of about 600 movies, we find that contextual information disappears after about 60 milli-seconds. This finding might suggest temporal limits that may apply to neuronal mechanisms tuned to regularities in natural scenes.

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26.540 Anisotropy in Paintings: A reflection of structural anisotropy in natural scenes?

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A number of recent studies have compared the statistical regularities of natural scenes to those of paintings (e.g., Graham & Field, Perception 2008; Graham, Friedenberg, & Rockmore, VisCog 2010). The theory behind such investigations is that art may reflect coding biases inherent in human vision since art is created to be "effective" when viewed by the visual system. Several studies (e.g., Graham & Field, Spatial Vis 2007; Redies et al., Network 2007) have shown that structural content in art work show a bias of scale that is similar to that of natural scenes – a linear fall-off of amplitude with spatial frequency. However, natural scenes also tend to be anisotropic with most power at horizontal, next most at vertical, and least at the 45o obliques (e.g., Hansen & Essock, JOV 2004). Furthermore, a corresponding anisotropy (the "horizontal effect") appears to be inherent in the coding of orientation by the visual system (Essock et al., JOV 2009). A comparable anisotropy in paintings may depend on scene content and painting style, but representational paintings of natural scenes, and perhaps other types of content, would be expected to contain this bias. The current investigation seeks to compare orientation anisotropies found in natural scenes to the orientation content in certain classes of paintings. Paintings were photographed in several museums. To avoid bias associated with different orientations, the camera was rotated obtaining images every three degrees. A Fast Fourier transform (FFT) was performed in Matlab on the images and average amplitude extracted at 0o and 90o. From this set of image transforms, the full 180o of content was obtained (see Methods in Hansen & Essock, 2004). For most painting types, results confirm prior reports of "1/f" structural relationship and also support our conjecture of a horizontal effect anisotropy.

26.541 Characterizing the salience and interactions of informative image statistics

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Visual perception of natural scenes depends on the processing of image statistics. They can drive segmentation of an image into objects, indicate the material composition of a surface, and provide the gist of a scene. To study visual processing of image statistics via natural scenes, however, is daunting: the statistics of natural scenes constitute a high-dimensional set of parameters that are intertwined in a complex fashion. Recent results concerning high-order statistics of natural scenes (Tkačik et al., PNAS 2010) suggest a way to make this problem tractable. This analysis showed that only certain kinds of high-order statistics are informative about natural scenes; other kinds of statistics can be estimated accurately from simpler quantities and, additionally, are not salient to human observers. Based on this identification of informative statistics, we construct a model "texture space" of binary images, in which textures are specified by the frequency of the colorings of 2x2 blocks of pixels. Once these local statistics are specified, long-range statistics are chosen to make the textures as random as possible. The resulting texture space has 10 dimensions. Its coordinates consist of first-, second-, third- and fourth-order image statistics, each of which is visually distinctive. We used a standard segmentation task (4-alternative forced-choice) to determine the perceptual salience of the individual statistics and how they interact. Results are strikingly consistent across N=6 observers, both qualitatively and quantitatively. With regard to individual statistics, thresholds for the first-, second-, third-, and fourth-order statistics are in a ratio of approximately 1:2:5:4. With regard to interactions, we find

(i) that statistics interact across orders, and (ii) that third-order statistics are pooled across orientations to a greater extent than second-order statistics. Together, these studies map out the geometry of a perceptual space, and provide constraints for models of the neural computations that generate it. Acknowledgement: NIH NEI 07977

26.542 A neural population model for pattern detection

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Behavioural pattern detection experiments have greatly advanced our understanding of the computations performed by the early visual system to extract information from the retinal image. Up to now, psychophysical near-threshold measurements have been taken to suggest that observers select the maximum response from a bank of parallel linear visual filters, each sensitive to a specific image resolution, to perform detection. However, spatial-frequency tuned neurons in primary visual cortex are neither linear, nor independent and ample evidence emphasizes that perceptual decisions are mediated by pooling responses of multiple neurons. Why then does the aforementioned model do so well in explaining pattern detection? One possibility is that near-threshold stimuli are too weak to drive the early visual system's nonlinearities and activate only few sensory neurons. Alternatively, the ability of this theory to account for threshold experiments modelled in isolation belies the fact that its assumptions about pattern detection are inherently wrong. Here, we challenge both a linear channel model (LCM) and a neural population model (NPM) to fit a broad range of well-known and robust psychophysical pattern detection results, using a single set of parameters. In the LCM, psychophysical decisions reflect maximum-output decoding of linear and independent spatial frequency channels. In the NPM, perceptual choice behaviour is driven by maximum likelihood decoding of a population of normalized spatial-frequency tuned units resembling V1-neurons. We find that the LCM fails to satisfactorily explain pattern detection. The NPM, on the other hand, can fully account for pattern detectability as investigated in behavioural summation, adaptation and uncertainty experiments. This work thus offers a new theoretical interpretation for the vast psychophysical literature on pattern detection in which both normalization and maximum-likelihood decoding turn out to be crucial.

26.543 Decoding cortico-cortical receptive fields: Background signal fluctuations in the visual system are retinotopically coordinated between different visual areas

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In this study, we assessed whether fMRI can be used to measure cortico-cortical receptive fields (CCRF). In other words, we investigated which regions within the retinotopic map of one visual area are most informative for the prediction of the time course of a single voxel in another visual area. In 8 blindfolded subjects, we measured resting state fMRI (eyes closed) of the visual occipital cortex (TR=1.5 sec). In addition, the visual areas of each subject were mapped by standard retinotopic mapping. Then, the activation of all voxels within visual areas V1 and V3 was extracted for the resting state data. Using a support vector regression, we calculated a connectivity map defined by the regression coefficients that allowed for the best prediction of responses of single voxels in V3 given the multivariate responses in V1. Finally, the CCRF of all voxels in V3 were averaged to obtain a single topographic connectivity structure (TCS) between V1 and V3 for each hemisphere. Importantly, the averaging procedure was performed in the functional, i.e. retinotopic space, and thus did not directly depend on the individual anatomical structures of subjects. The resulting TCS between the two visual field maps show that even without any visual input the connectivity structure conserves the retinotopy. Resting state activations in single voxels in V3 are best predicted by sampling from regions within V1 that have similar retinotopic positions. In summary, despite the relatively low temporal and spatial resolution, it is possible to measure detailed functional connectivity structures with fMRI based on spontaneous fluctua-

tions. Importantly, we have exploited the retinotopic organization of visual cortex to investigate the average functional connectivity structure between complete visual maps in functional coordinates. The method presented here can potentially be used to investigate functional connectivity between any kinds of topographically organized regions in the brain.

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26.544 Spatial saturation in human visual cortex

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Integrating image features across space is fundamental to visual function. Previous fMRI studies investigating retinotopy and related spatial properties have assumed implicitly or explicitly that responses to spatial contrast patterns sum linearly over the visual field. To test this assumption, we measured BOLD activity in human visual cortex while subjects viewed brief presentations of contrast patterns seen through horizontal and vertical apertures. A variety of different apertures were presented in random order in an event-related design. Throughout visual cortex the response to a large aperture was less than the sum of the responses to two parts of the aperture shown in separate trials. This sub-additive effect was larger in extrastriate areas than in V1. We modeled the sub-additivity by incorporating a compressive nonlinearity into a basic linear model of population receptive fields (Dumoulin and Wandell, 2008; Kay et al., 2008). Using cross-validation to obtain unbiased measures of model accuracy, we found that the nonlinear model systematically outperforms the linear model, explaining up to 98% of the variance in the amplitudes of the responses to the various apertures. Moreover, the nonlinearity of the model was more pronounced in extrastriate areas, consistent with the larger degree of sub-additivity in these areas. The nonlinear effect we have described can be viewed as spatial saturation in the sense that stimulating only a portion of a population receptive field is sufficient to saturate the response. Spatial saturation reduces sensitivity to changes in the position of a viewed object, and may be a fundamental computation that underlies the emergence of position tolerance in extrastriate areas.

Acknowledgement: NIH grant EY019244, NEI grant RO1-EY03164

26.545 ERP correlates of orientation-specific surround suppression

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Surround suppression—the reduction in perceived contrast of a center stimulus and the visual response to that stimulus in the presence of a high-contrast surround—is greatest when the center and surround stimuli share the same orientation. We examined the electrophysiological correlates of orientation-specific surround suppression using event-related potentials (ERPs). Displays contained a circular sinusoidal grating consisting of separate annulus (center) and surround regions. On each trial, the surround was presented in isolation for 500-1000 ms, followed by the annulus (with continuing presentation of the surround) for 400 ms. ERPs in response to the onset of the annulus were recorded for different annulus and surround orientations. In separate blocks, we varied the orientation of the surround grating such that it was either parallel or orthogonal to the annulus. Participants performed a contrast decrement detection task within the annulus, and the contrast of the target was adaptively varied using a psychophysical staircase procedure in order to equate task difficulty across all conditions. We measured contrast-decrement detection thresholds and P1 and N1 components of the ERP responses to the onset of the annulus for both parallel and orthogonal orientation conditions. Behaviorally, we found orientation-specific surround suppression: contrast decrement detection performance was worse when the surround had the same (parallel) orientation compared to when the annulus and surround were orthogonally oriented. In addition, amplitudes of the P1 and N1 components of the response to the annulus were smaller when the annulus was presented within a parallel, compared to an orthogonal, surround. Finally, behavioral indices

of orientation-specific surround suppression for individual subjects were positively correlated with the magnitude of orientation-specific surround suppression of ERP amplitudes.

26.546 Does the BOLD signal reflect input or output of a cortical area? -- Laminar patterns of Gamma-band activities in Macaque visual cortex

Dajun Xing¹(dx204@nyu.edu), Chun-I Yeh¹, Samuel Burns¹, Robert Shapley¹;
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fMRI has been widely used for basic and clinical studies. While cortical neural activity varies with changes of cortical depth of less than 0.2 mm, the BOLD signal averages over voxels of 1-3 mm on a side. This leads to an open question: does BOLD pool brain activity evenly from all layers in a cortical region or it is dominated by signals from some particular layers?

We tried to answer this question by measuring the laminar patterns of Gamma-band activity in Macaque primary visual cortex (V1). The rationale was: if gamma-band activity in the local field potential (LFP) is related to BOLD, as several studies (Logothetis 2001 & Goense and Logothetis 2008) have claimed, the laminar pattern of gamma activity should indicate which cortical layers contribute to the BOLD signal.

We measured the LFP in V1 visually driven by a large patch (2-3deg in radius) of sinusoidal grating drifting in different directions (0 to 360 deg, 30 deg intervals) at high contrast (99%) as well as at zero contrast (blank screen). With track reconstruction, we identified the cortical depth for each recording site, and then studied the visually-driven activity in the gamma-band as a function of cortical depth.

From 315 recording sites in 6 anaesthetized monkeys, we found gamma activity was strongest in layer 4B and layer 2/3. Gamma-power was generally weaker in the deep layers with a sharp drop in gamma power at the border of layer 4C α and 4C β : layers 4C β , 5 and 6 showed weaker gamma power.

Our results suggest that 1) V1's BOLD signal will be dominated by gamma-power in layers 2/3 and 4B; 2) the BOLD signal reflects activity in the output instead of the input layers; 3) the BOLD signal is most influenced by activity in cortical layers with strong recurrent connections.

Acknowledgement: This work was supported by NIH-EY001472, NIH-EY007158, NSF-0745253, the Robert Leet and Clara Guthrie Patterson Trust Postdoctoral Fellowship, and the Swartz Foundation.

26.547 How receptive field properties of V1 neurons change with different stimulus ensembles

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Many V1 simple cells show a strong contextual effect - their receptive fields vary when measured with different stimulus ensembles. By using Hartley subspace (HS, Ringach et al, 1997) and sparse noise (SN, Jones and Palmer, 1987) stimuli to map monkey V1 receptive fields, we showed that the contextual effect was bigger for output layer-2/3 than for input layer-4c neurons (Yeh et al, 2009). In comparison to HS maps, SN maps of layer-2/3 neurons have shorter aspect ratios, smaller numbers of subfields, and show greater black-dominance (stronger OFF-subregions, Yeh et al, 2009). It remains unclear what stimulus parameters are critical for the observed changes in receptive field properties. Here we introduced a third stimulus ensemble - a binary checkerboard white noise (WN, m-sequence, Reid et al, 1997) to map the receptive field. WN and HS are dense stimuli that activate simultaneously a larger population of neurons than SN. Unlike HS stimuli, neighboring pixels of WN and SN stimuli are uncorrelated. Receptive fields measured with the three different stimuli were fitted with a two-dimensional Gabor function. For layer-2/3 simple cells ($f1/f0 > 1$), we found: 1) the aspect ratio of HS maps (3.22+1.43, mean+s.d.) was significantly larger than that of WN (1.83+0.61) and SN maps (1.48+0.24); 2) the number of subregions was largest for HS (3.10+1.36), followed by WN (1.80+0.39), and smallest for SN maps (1.33+0.24); 3) black-dominance, as measured by the spatial phase angle of the best-fitting Gabor function (0 $^\circ$: white dominated, 90 $^\circ$: white/black balanced, 180 $^\circ$: black dominated), was more evident for SN (155 $^\circ$ +29.8 $^\circ$) than for HS (116 $^\circ$ +54.1 $^\circ$) and WN (133 $^\circ$ +38.8 $^\circ$). These results suggest that measurement of more elongated subfields, and more

subregions, may be attributed mostly to spatial correlations of the HS stimuli, but the strong black dominance in layer-2/3 cells can be attributed to the spatial sparseness of the SN stimuli.

Acknowledgement: NIH-EY001472, NSF-0745253, NIH-EY007158, the Robert Leet and Clara Guthrie Patterson Trust Postdoctoral Fellowship, and the Swartz Foundation

26.548 Estimating the growth of discriminative information guiding perceptual decisions

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Perceptual decision-making is thought to involve a gradual accrual of noisy sensory evidence. Temporal integration of the evidence reduces the relative contribution of dynamic internal noise to the decision variable, thereby boosting its signal-to-noise ratio. We aimed to estimate the discriminative quality of the internal representations guiding perceptual decisions over time, using a novel combination of external noise and signal-to-respond methods. Observers performed orientation discrimination of patterns presented in external noise. We varied the contrast of the patterns and the delay at which observers were forced to signal their decision. Each test stimulus (patterns and noise sample) was presented twice. Analysis of performance at a single contrast level showed that accuracy conformed to a standard 'speed-accuracy' curve: discrimination accuracy improved over time according to an exponential growth function. However, observer model analysis of discrimination accuracy and response consistency to two passes of the same stimulus, suggested very little growth in discriminative information. The improvement in performance over time predominantly reflected a decreasing proportion of non-visual, or purely random, decisions. The standard speed-accuracy growth curve collected in signal-to-respond paradigms is therefore not necessarily indicative of an improvement in discriminative quality of the internal representations guiding decision-making. The relative constancy of the discriminative information over time suggests that the dominant source of internal noise limiting performance is static and cannot be compensated for by prolonged evidence integration.

Acknowledgement: Engineering and Physical Sciences Research Council

26.549 Contrast-response functions, Fisher information, and contrast decoding performance

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Using maximum a posteriori decoding of stimulus contrast, Clatworthy, Chirimuuta, Lauritzen and Tolhurst (2003, Vision Research, 43, 1983-2001) discovered many characteristics of the relationship between the contrast-response function [described by the Naka-Rushton function, $r = r_{max}cq / (c_{50}q + cq)$] and contrast identification accuracy. Their decoding method is optimal, but laborious to implement, and gives little insight into why these characteristics arise, or how general they are. If the spike count is not too low, the Fisher information provides a good analytical approximation of optimal decoding accuracy. We show how to calculate the Fisher information for Clatworthy et al.'s doubly stochastic Poisson process, and derive equations that explain many of their observations regarding single neurons, e.g. that accuracy peaks "slightly below the neuron's c_{50} " (Clatworthy et al., p. 1989) - we show that it peaks at the contrast for which mean response is $r_{max}/3$. Fisher information provides a closer estimate of optimal decoding accuracy for neural populations than for single neurons because of the higher total spike count. We show that, for a population of $N \geq 8$ Poisson-spiking neurons with $q = 2$ and c_{50} values evenly distributed across the log contrast range, $\log_{10} c E [-3, 0.1]$, Fisher information very closely approximates optimal contrast decoding accuracy when $N \times r_{max}$ is greater than about 100 spikes; in these conditions, decoding accuracy is very close to being proportional to $N \times r_{max}$. We also investigate the effect of supersaturation, whereby the contrast-response function peaks and then declines with increasing contrast. Contrary to the proposal that supersaturating neurons provide a suboptimal contrast code [Peirce, 2007, Journal of Vision, 7(6):13, 1-10], we show that supersaturation improves contrast decoding accuracy for neural populations, while also reducing metabolic costs.

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26.550 Psychophysical evidence for normalization in second-order mechanisms

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Objective: We hypothesize a cascade model of cortical processing in which the same canonical computations (linear filtering, F, rectification, R, and normalization, N) are repeated across a hierarchy of stages (F1R1N1, F2R2N2, etc). We tested for the existence and orientation selectivity of 2nd-stage normalization (N2).

Methods: Stimuli were either contrast-modulated (CM) or orientation-modulated (OM) 2nd-order stimuli with bandpass noise carriers and low-frequency sinusoidal modulators. Observers performed a 2AFC task to identify which segments of an annular target region contained 2nd-order modulation. The target was either presented alone or embedded in a surround (inside and outside of the annulus). Three types of surround stimuli were used: no 2nd-order modulation, or 100% modulation amplitude in which the modulator orientation was either parallel or orthogonal to the target modulation. For each condition, we estimated the 2nd-order modulation depth for the target corresponding to discrimination threshold.

Results: Four out of four subjects (for CM stimuli) and four out of five subjects (for OM stimuli) showed significant threshold elevation in the full-modulation-surround conditions compared to the zero-modulation-surround condition, indicative of normalization. For CM stimuli, all subjects showed an orientation-specific effect, exhibiting higher thresholds for parallel than for orthogonal surrounds. For OM stimuli, 2nd-order surround suppression was not consistently orientation-selective. In no case was there evidence of significant 1st-order surround suppression (zero-modulation vs. target-alone conditions).

Conclusion: 2nd-order spatial coding uses similar computations to 1st-order, including normalization (surround suppression). For some forms of 2nd-order modulation, normalization is orientation-selective.

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26.551 A Neural Model of Figure-Ground Segregation Explains Occlusion Without Junction Detectors

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T-junctions, created by the intersection of contours separating three different luminance values, are often said to provide local information about occlusion in visual scenes. Although neurophysiological studies provide little support for cells serving as junction “detectors”, many neural models of figure-ground segregation, such as Finkel & Sajda (1992, Neural Computation), determine occlusion by assuming such cells exist. Border-ownership cells identified in physiological studies by Zhou et al. (2000, Journal of Neuroscience) demonstrate side-of-figure and occlusion sensitivities even at non-junction contours, thereby integrating global grouping information, presumably through feedback. We present a biologically plausible neural model of primate visual areas V1 and V2 that performs figure-ground segregation using grouping circuits without dedicated junction mechanisms. Our model LGN’s on-center/off-surround competition is followed by oriented contrast detection by V1 complex cells. We use border-ownership cells that receive feedback from grouping cells that respond to convexity, similar to those of Craft et al. (2007, Journal of Neurophysiology). We assume these cells assert “figureness”, but they inherently face a static aperture problem. For instance, individual grouping cells can only resolve T-junctions as two L-junctions, which do not signal occlusion. We therefore use another layer of grouping cells that, through competitive feedback across scale, can correctly vote for occlusion using a winner-take-all network, consistent with human judgments of synthetic and natural T-junctions presented through an aperture in McDermott (2004, Perception). Our model also explains why humans report occlusion in one but not both of the E-shaped occluders of Rubin (2001, Perception), and in more general visual displays, such as the Kanizsa square and transparent regions. This suggests that the visual system may not rely on specialized junction circuits to perform figure-ground segregation. Occlusion information conferred by T-junctions may reflect a more general process of inter-scale competition of grouping cells sensitive to local convex regions.

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Sunday Morning Talks

Motion: Encoding and aftereffects

Sunday, May 8, 8:00 - 9:45 am

Talk Session, Royal Palm 1-3

Moderator: Hinze Hogenboom

31.11, 8:00 am

Large illusory displacements of spots flashed on a moving object.

Stuart Anstis¹(sanstis@ucsd.edu), Patrick Cavanagh²; ¹Psychology, UCSD, ²LPP, Université Paris Descartes

When a test is briefly flashed adjacent to a moving stimulus, its perceived position is dragged in the direction of the nearby motion (Whitney & Cavanagh, 2000). Here we show that if the test was flashed on top of the moving stimulus, its perceived displacement increased by up to 400%. This large displacement was seen only if the moving stimulus oscillated back and forth and the test appeared near the moment at which the motion reversed. It was the motion following the test flash that determined the direction of illusory displacement, and the illusory displacement fell off sharply if the flash occurred a few hundred ms before or after the motion reversal. In a second condition, rather than flashing a test on top of the moving stimulus, we briefly changed the color of part of the moving stimulus (Cai & Schlag, 2001). Here as well there was a large illusory displacement of the flashed part of the stimulus but this displacement was not much affected by the timing of the flash relative to the motion and could be seen even for continuous motion. Moreover, the flashed component of the object did not seem displaced relative to the rest of the object, suggesting that the entire stimulus was extrapolated in the direction of motion, not just the flashed component. This difference between a flash on top of a moving object and a flash of part of an object may reveal the conditions that cause a brief flash to be interpreted as part of a moving object when it occurs at a moment of motion uncertainty, as opposed to an unrelated transient when it occurs after the object's motion is well established.

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31.12, 8:15 am

Optimal signal integration across spatiotemporal frequency channels accounts for perceived visual speed

Matjaz Jogan¹(mjogan@sas.upenn.edu), Alan A. Stocker¹; ¹Department of Psychology, University of Pennsylvania

Humans can optimally integrate sensory cues across different perceptual modalities in order to form a coherent percept (Ernst/Banks 2002). Here, we propose that optimal integration also occurs within a single perceptual modality. More specifically, we hypothesize that the perceived retinal speed of a translating intensity pattern results from a Bayesian integration of sensory signals across independent spatiotemporal frequency channels, combined with a prior expectation for slow speeds (Stocker/Simoncelli 2006).

In order to validate our hypothesis, we had four subjects perform a 2AFC visual speed discrimination task. The reference stimulus was a broad-band compound grating drifting at a speed of 2 deg/s. Test stimuli were either drifting sinewave gratings of one of two spatial frequencies (0.4 or 1.2 cycles/deg, respectively; at 30% contrast), or their superposition in either a "peaks-add" or a "peaks-subtract" phase configuration. We measured full psychometric curves for all conditions using an adaptive staircase procedure. We found that all subjects perceived the single spatial frequency gratings moving slower than their superpositions, with the low frequency grating being perceived the slowest. However, we did not find any significant difference in perceived speeds between the combined grating stimuli in "peaks-add" and "peaks-subtract" configuration, despite the fact that the effective contrast of both configurations differs by 30%.

The measured perceived speeds are consistent with the predictions of a Bayesian observer model that optimally integrates sensory signals of two independent spatiotemporal frequency channels each responding to one of the two grating stimuli, in combination with a prior for slow speeds. Fits of the observer model to individual subjects' data well account for the full set of psychometric functions. The estimated parameters for prior and likeli-

hoods are consistent between subjects and comparable with values suggested in previous studies. Our results potentially lead to improved models of coherent motion perception of more complex stimuli.

31.13, 8:30 am

The motion-induced position shift of a Gabor patch with a moving carrier and a moving envelope viewed with a moving eye

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The static envelope of a Gabor patch with a moving carrier appears shifted in the direction of the carrier motion (motion-induced position shift; MIPS). Such a conventional configuration contains at least three co-varying factors, i.e., the retinal carrier velocity, the environmental carrier velocity, and the carrier-envelope velocity difference. To elucidate which factor is critical, we independently manipulated them and measured the perceived position of the moving Gabor patch. We presented two vertically aligned Gabor patches, a reference patch and a test patch. The reference contained a horizontally oriented static carrier, whereas the test contained a vertical carrier drifting in various velocities. The envelopes of the reference and test patches moved coherently to the left or right at 2.5 deg/s. By asking each subject to judge the relative horizontal position between the reference and test, the position of subjective alignment was established as the index of illusion strength. In the first experiment, the MIPS of the moving envelope was observed during fixation; the perceived position of the moving envelope shifted in the direction of the carrier. Furthermore, the MIPS was greater when the carrier moved oppositely to the envelope motion. In the second experiment, we measured the MIPS during smooth pursuit eye movements to the left or right at 2.5 deg/s, with the envelopes of the patches being either static or moving in the pursuit velocity, thereby dissociating retinal and environmental velocities. Under all conditions the MIPS was induced in the retinal direction of the carrier. Also, the MIPS was greater when the movements of the carrier and envelope were opposite to each other in retina-centered coordinates. We conclude that the retinal velocity of the carrier is the primary determinant for the MIPS, and we will discuss possible additional contribution of mechanisms detecting the motion contrast between the carrier and envelope.

31.14, 8:45 am

Decoding the motion aftereffect in human visual cortex

Hinze Hogendoorn¹(j.h.a.hogendoorn@uu.nl), Frans A.J. Verstraten¹; ¹Department of Experimental Psychology, Utrecht University

In the motion aftereffect (MAE), adapting to a moving stimulus causes a subsequently presented stationary stimulus to appear to move in the opposite direction. Recently, the neural basis of the motion aftereffect has received considerable interest, and a number of brain areas have been implicated in the generation of the illusory motion. Here, we use functional magnetic resonance imaging in combination with multivariate pattern classification to directly compare the neural activity evoked during the observation of both real and illusory motion. We show that the perceived illusory motion is not encoded in the same way as real motion in the same direction. Instead, suppression of the adapted direction of motion results in a shift of the population response of motion sensitive neurons in MT+, resulting in activation patterns that are in fact more similar to real motion in orthogonal, rather than opposite directions. Although robust motion selectivity was observed in visual areas V1, V2, V3, and V4, MAE-specific modulation of the population response was only observed in MT+. Implications for our understanding of the motion aftereffect, and models of motion perception in general, are discussed.

Acknowledgement: NWO Pionier

31.15, 9:00 am

A new form of motion aftereffect in transparent motion adaptation

Alan L. F. Lee¹(alanlee@ucla.edu), Hongjing Lu^{1,2}; ¹Department of Psychology, UCLA, ²Department of Statistics, UCLA

Previous studies have found that adapting to orthogonal transparent motion patterns yields an integrated motion aftereffect (MAE) opposite to the average direction of the transparent motion. Here we demonstrate a

new phenomenon of segmented MAE opposite in direction to just one of the transparent components, and investigate the mechanisms that underlie the segmented and integrated MAEs. The 24-degree-wide adapting stimulus contained 396 randomly-oriented, equally-spaced Gabor elements. Half of the Gabors were assigned a global-motion direction of $X-45^\circ$ (pattern 1) and the other half $X+45^\circ$ (pattern 2), where X is the integrated direction of the two pattern vectors. After 45s of adaptation, observers reported the MAE direction when tested with static Gabor elements shown at different locations. In Experiment 1, when test Gabors were presented at locations from both adapting patterns, an integrated MAE was found, with the aftereffect direction opposite to the integrated direction (i.e., $X-180^\circ$). However, when all test elements were at locations from one adapting pattern (e.g., pattern 1), a segmented MAE was obtained, with the aftereffect direction opposite to that pattern's adapting direction (e.g., $X+135^\circ$). MAE changed from segmented to integrated when test orientations were orthogonal to adapting orientations (Experiment 2), and when test Gabors were presented at "phantom" locations, at which no adapting elements had been presented (Experiment 3). The results of Experiment 1 imply that both segmented and integrated motions are represented during transparent motion adaptation, as different test stimuli can reveal either form of MAE. The reemergence of integrated MAE in Experiment 2 demonstrates a dominant role of integration processing when local adaptation was weakened. The "phantom integrated MAE" found when local adaptation was eliminated in Experiment 3 provides further support for this interpretation. Our findings demonstrate the interaction between two distinct motion-adaptation mechanisms, which may be crucial when adapting in dynamic environments.

Acknowledgement: This research was supported by NSF grant BCS-0843880 and UCLA Faculty Research Grant

31.16, 9:15 am

Motion integration across apertures generates a global motion aftereffect in an unadapted region

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The motion of a straight edge seen through a single aperture is inherently ambiguous, known as the aperture problem. While the phenomenal direction perception is usually perpendicular to the orientation of the edge in a circular aperture and thus does not directly specify the motion direction of objects in the environment, the true direction of object motion could be discovered by appropriately integrating motion across multiple apertures. How does this integration affect the motion processing in the occluded regions of the moving object outside of the apertures? Following exposure to diamond-shaped objects moving behind an occluder with only part of the four edges visible through four circular apertures, we observed a motion aftereffect with a dynamic test patch presented in an area not overlapping with any of the apertures, the effect of which is consistent with adaptation to global motion through integration of local apertures. There was no motion aftereffect when the same local motions within the four apertures were presented out of synchrony and could not be integrated. This suggests that the observed motion aftereffect could not be explained by simply summing the local motion energies and instead dependent on the emergent global motion perception of the partially occluded object.

Acknowledgement: NIH R01 EY015261

31.17, 9:30 am

What is the spatial integration area for global motion perception in human central vision?

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To determine the global (overall) direction of image motion the human visual system must integrate local motion signals across space and time. However, the spatial extent over which this integration process operates in central vision is uncertain. Previous studies that have measured direction discrimination for random-dot-kinematograms (RDKs), suggest that the spatial integration limit for global direction is at least as large as 63 deg2 (e.g. Watamaniuk & Sekuler, 1992; Vision Research 32: 2341-2347). However the total area of retinal stimulation and the dot number (to maintain dot density) both co-varied with changes in RDK size. Consequently, regional variations in motion sensitivity across space and the availability of local motion samples potentially confound these estimates. To address this issue we developed a novel display that enabled us to measure the global

motion integration area without changing the overall stimulus dimensions, dot number and density. Global motion coherence thresholds (79% correct) for direction discrimination were measured binocularly for 5 observers using RDKs in which the signal dots (all moving either up or down at 3.91 deg/s) were confined to a central, circular region of the display. The surrounding annular region only contained randomly moving noise dots. The spatial extent of the signal-dot-region varied from 1.95 to 249.14 deg2, but overall RDK size (249.14 deg2) and dot number (1024) remained constant. Coherence thresholds should be constant when all the signal dots are within the spatial integration area for global motion, but rise proportionally once this is exceeded. Results showed that the integration area for global motion was, on average, 12 deg2 and was unaffected by a log-unit change in dot contrast (100 to 10 %). The size of this integration area in humans is consistent with physiological measurements of foveal-centred receptive fields in primate area MT.

Acknowledgement: Wellcome Trust (PM) Chief Scientist Office Scotland (AS)

Object recognition: Features

Sunday, May 8, 8:00 - 9:45 am

Talk Session, Royal Palm 4-5

Moderator: Gabriel Kreiman

31.21, 8:00 am

The medial axis structures of novel objects are spontaneously perceived despite variability in the objects' orientations and component part shapes

Mark D Lescroart¹(lescroart@usc.edu), Irving Biederman^{1,2}; ¹University of Southern California, Neuroscience Graduate Program, ²University of Southern California, Department of Psychology

Evidence from imaging, electrophysiology, and behavior supports the idea that objects are represented as collections of parts, but few studies have investigated how the spatial relationships between parts are represented. Such relations are critical since changing them can change the object, just as changing the order of phonemes can change the meaning of a word (e.g., "rough" and "fur"). One way to define relationships between objects' parts is to specify a medial axis within each part. These axes can define an invariant structure of an object, since relationships between medial axes will be constant despite variation in view. Previously, we showed that multi-voxel patterns in intermediate visual areas can distinguish groups of objects with distinct medial axis structures, even if the objects' parts differ and the orientations of the objects vary (Lescroart & Biederman, VSS 2009). Would naïve human subjects spontaneously judge different novel objects with the same axis structures to be similar, despite variation in other dimensions? In an "inverse multidimensional scaling" paradigm, naïve subjects rated the similarity of a set of novel objects that varied in medial axis structure, in the parts that composed the objects, and in overall orientation. On each trial subjects viewed a display of five objects, with instructions to place similar objects close together, and dissimilar objects farther apart. The distance between the centers of each pair of objects was recorded as the dependent measure. In contrast to prior sorting studies, in which subjects grouped objects based on a single part or dimension, non-metric multi-dimensional scaling revealed that subjects prioritized both the objects' parts and the objects' medial axis structures in their similarity judgments. These results, together with the fMRI results, suggest that axis structures are automatically computed by the visual system, and spontaneously used as the basis for perceptual similarity judgments.

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31.22, 8:15 am

What determines the canonical view of a scene?

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Although familiar objects can be recognized from any angle or orientation, there seems to be a preferred viewing angle for most objects. This view, called the "canonical" view (Palmer, Rosch, & Chase, 1981), is the view produced when people are asked to imagine or photograph an object. Are there canonical views of scenes? To answer this question, we conducted an online experiment using 624 panoramic images, which capture the full

360-degrees view around a single location. Observers used an interactive viewer to explore these panoramic scenes and select the “best view” of each location.

We found that agreement on the “best view” of these scenes was generally high. Agreement was higher in indoor scenes than outdoor, probably due to differences in the shape of the scene (agreement was higher in scenes with smaller overall volume and in scenes with a range of visible depths). View agreement was also correlated with name agreement (agreement was higher in scenes with unambiguous names than in scenes which elicited multiple names).

A “volume map” was created for each scene which measured the percentage of the total scene visible in each direction around the camera. We also created a “navigational map” based on the locations of navigational paths (eg, sidewalks, paths between furniture). We tested how well these maps predicted the views chosen by observers (as measured by the area under the ROC curve, AUC). We found that the volume map best predicted the views selected by observers (AUC = 0.75), and although the navigational map performed above chance (AUC = 0.62), it provided no independent predictive power over the volume map. This suggests that the “best view” of a scene is the view which maximizes the amount of visible space, not necessarily a view based on functional constraints such as navigational paths.

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31.23, 8:30 am

Segmenting 2D Shapes using 3D Inflation

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Given an arbitrary 2D silhouette, human observers can readily segment it into parts; these same observers generally agree on whether a segmentation looks correct, suggesting a regularity in how humans perceive 2D parts. As a result, considerable work has been done to understand what drives this part segmentation. Hoffman and Richards proposed the Minima Rule, in which endpoints of part boundaries are located at local minima of negative curvature. The rule succeeds at explaining many segmentation phenomena, but has many well-known limitations, including a lack of systematic rules for pairing boundary endpoints and numerous exceptions. Later models, such as the Shortcut Rule and Necks and Limbs, have added auxiliary rules to patch these holes, but they lack the simplicity of the original Minima rule, require careful parameter tweaking, and still contain significant exceptions. We propose a new approach which is both simple and effective, and largely parameter free. Rather than working directly on the 2D contour of the silhouette, we construct a 3D shape that fits the contour, using a simple inflation algorithm that we call Puffball. Puffball places spheres along the medial axis of the silhouette; the union of these spheres is smooth, fills the original silhouette, and gives an intuitive result. This inflation exhibits natural breakpoints, marked by creases of negative curvature on the top of the inflated shape. Bridging these breakpoints across the silhouette using the medial axis results in an intuitive part segmentation on numerous shapes, even those which foiled previous approaches. Also, these part boundaries can be ranked in strength to create a hierarchy of parts. Thus, our part segmentation algorithm begins and ends in 2D, but by moving our analysis to 3D, we arrive at an approach which is simpler, more intuitive, and far more reliable.

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31.24, 8:45 am

Can configural relations be encoded by image histograms of higher-order filters?

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A popular method for representing images is to compute histograms of pixel intensities, wavelet responses, or the outputs of more complex filters that are tuned to specific shapes (e.g. Riesenhuber & Poggio, 1999). Because these representations do not retain the locations of the activated filters, they may not be well suited for the analysis of configural relations among image features. The present study was designed to address this issue.

Method: We created 4 classes of objects based on the classic Vernier acuity and bisection tasks. Each object was composed of 3 irregularly shaped white dots embedded in a larger irregular black disc. Class membership was determined by whether the dots were arranged collinearly and whether they were equally spaced. Naive observers were trained to classify the stimuli in two separate conditions: One in which they were trained and tested with all possible stimulus orientations, and a second in which they were trained with one set of orientations and then tested with another. We also evaluated these same two conditions using a recent implementation by Mutch & Lowe (2006) of the HMAX model originally developed by Riesenhuber & Poggio (1999).

Results: Most subjects exceeded 85% accuracy in both conditions after ~180 exposures to each class. Performance was much worse for the HMAX model. When trained with 300 images from each class, its average classification accuracy was only 31%, and was reduced to chance (i.e. 26%) in the transfer condition.

Conclusion: Human observers can easily learn to classify objects based on configural properties such as collinear alignment or bisection, but similar performance cannot be achieved using histograms of higher order features as implemented in the HMAX model. These findings identify an important limitation of representing images with histograms of filter activations without retaining the relative spatial locations of those filters.

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31.25, 9:00 am

Binding the features of a continuously changing visual stimulus

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Consider a disk that is changing along a continuum of color over two seconds, from red to green. If the disk is yellow after one second, and at this same instant a second yellow disk is presented as a brief pulse, the color of the continuously changing disk is perceived to be ahead on the color continuum (say, greenish yellow) compared to the pulsed disk (Sheth, Nijhawan & Shimojo, 2000). Chromaticities of both disks are identical when the pulse is presented but the two disks are perceived to be different. Similar results hold for luminance, spatial frequency and pattern entropy but the lead times vary for different features (for example, longer for color than spatial frequency). How is our percept affected by the combination of features that have different lead times?

METHOD: A circular window (diameter 2.6deg) with a 1.3cpd square-wave grating appeared on one side of a fixation point. The color of the grating changed continuously, either from green to red or from red to green; simultaneously, the grating rotated either clockwise or counter-clockwise. Exactly halfway through the presentation, a second stimulus was briefly presented (79msec) on the other side of the fixation point. The color and orientation of the pulsed grating were the same as the continuously changing grating at that instant. At the end of each presentation, the observer compared the pulsed stimulus to the continuous one in (1) only color, (2) only orientation or (3) both.

RESULTS & CONCLUSIONS: When color or orientation was matched alone, color showed longer lead times than orientation. When observers matched both color and orientation simultaneously, the lead times for color were still substantially longer than for orientation. This implies that observers perceived the continuously changing stimulus to have a combination of orientation and color that was never actually presented to the eye!

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31.26, 9:15 am

Top-down signals are needed for object completion in the human visual cortex

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Objects are often partially occluded during natural viewing conditions. Therefore, visual recognition requires object completion mechanisms capable of extrapolating from partial information to infer the identity of objects. Here we combine psychophysics, theoretical modeling and neurophysiological recordings to further our understanding of the computations

involved in object completion. We record neurophysiological activity from subjects with intractable epilepsy who were implanted with electrodes to localize their seizure onset focus. We recorded intracranial field potentials from areas in the temporal lobe including inferior temporal cortex and the fusiform gyrus among other areas. Subjects were presented with brief flashes (150 ms) of objects viewed through small bubbles that only partially revealed the object. Subjects performed a five-alternative forced choice categorization task. Consistent with previous psychophysical studies, recognition from partial information led to longer reaction times. At the physiological levels we observed that electrodes in visual cortex maintained their visual selectivity in response to images containing only a small fraction of object information. The responses to the partially occluded images were smaller in amplitude and showed significantly longer latencies. Furthermore, physiological responses correlated with the subjects' performance on a trial-by-trial basis. We conjecture that these longer latencies reflect indirect evidence for a requirement for enhanced processing, possibly through top-down signals, of occluded objects. Consistent with this hypothesis, we consider a purely bottom-up model of object recognition and the effect of adding top-down signals to this feedforward model. Simulating the responses of the model to the same images used in the physiology and psychophysics, we show that top-down signals improve recognition performance under occlusion conditions.

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31.27, 9:30 am

Binding of text and speech by children

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Understanding text and speech requires several bindings, integrations of information. Our eyes combine letters to recognize a printed word. Our ears combine phonemes to recognize a spoken word. Sometimes we combine information from eye and ear, especially when learning to read. Dubois, Poeppel, and Pelli (submitted to Nature and VSS) assessed this audio-visual binding, showing that although adults inefficiently combine within a modality (e.g., letters or phonemes), they perfectly combine information from eye and ear. How does our ability to integrate features in text and speech develop? Here we probe how the bindings within and across modalities change as a function of age. Child and adult participants are asked to identify words presented concurrently through eye and ear, in both audio and visual noise. We vary the overall signal-to-noise ratio and the ratio of audio to visual signal energy. From age 6 to adulthood, we find that auditory and visual efficiencies increase by factors of 2.4 and 2, respectively. Assessing bimodal binding reveals that a 6-year-old, despite having much lower efficiency within each modality, already combines information from eye and ear perfectly, like an adult.

Acknowledgement: R01-EY04432 to D.G.P.

Multisensory processing

Sunday, May 8, 10:45 - 12:30 pm

Talk Session, Royal Palm 1-3

Moderator: Thomas Otto

32.11, 10:45 am

Multimodal integration for estimating event rates

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Separate lines of research have revealed that perceptual decisions about unreliable sensory information are driven by processes that integrate evidence across time or across modalities. Here we investigate the conditions under which subjects will integrate sensory information across both time and modalities. We presented subjects with multi-modal event streams, consisting of a series of noise-masked tones and/or flashes of light. Subjects made judgments about whether the event rate was high or low. Combining across modalities could improve performance in two ways: by improving the detectability of congruent auditory and visual events, or, more abstractly by combining rate estimates that are separately generated within each modality. Performance improved when stimuli were presented

in both modalities (cue-combination condition) compared to when stimuli were presented in a single modality. Importantly, this improvement was evident both when the auditory and visual event streams were played synchronously and asynchronously. The enhancement of rate estimates we observed for asynchronous streams could not have resulted from improved detection of individual events, which argues strongly that the subjects combined estimates of overall rates that were computed separately for auditory and visual inputs. Moreover, we show that subjects' performance agrees with a Bayesian statistical observer that optimally combines separate rate estimates for auditory and visual inputs.

32.12, 11:00 am

Interactive processing of auditory amplitude-modulation frequency and visual spatial frequency.

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Recent neurophysiological results suggest that crossmodal interactions are commonplace even in primary sensory areas of the brain. Spatial frequency is a fundamental visual feature coded in V1, and is relevant for perceiving scenes, hierarchical structure, and objects. Temporal amplitude-modulation (AM) frequency is a fundamental auditory feature coded in the primary auditory cortex, and is relevant for perceiving auditory objects and speech. Spatial frequency and temporal AM frequency are thus fundamental building blocks of visual and auditory perception. Here we demonstrate that the processing of auditory AM frequency and the processing of visual spatial frequency are closely associated. Observers linearly matched a given visual spatial frequency to a specific auditory AM frequency, suggesting a consistent perceptual mapping between visual spatial frequency and auditory AM frequency. This crossmodal association is not merely subjective; here we show that AM sounds modulate visual attention and awareness in a frequency specific manner. When a pair of Gabors with different spatial frequencies were simultaneously presented with an AM sound (perceptually matched to one of the Gabors), observers detected a phase-shift more rapidly when it occurred on the sound-congruent Gabor, suggesting that AM sound guided attention to the matched spatial frequency. When a pair of Gabors with different spatial frequencies were presented to separate eyes to generate binocular rivalry, presenting an AM sound (perceptually matched to one of the Gabors) increased the proportion of perceptual dominance of the congruent Gabor, suggesting that an AM sound boosts signal strength for the matched spatial frequency in processes that select stimuli for awareness. The naïve observers who participated in the binocular rivalry experiment were unaware of any association between AM sounds and Gabor spatial frequencies. Additional results suggest that the association between auditory AM frequency and visual spatial frequency develops through multisensory experience of manually exploring surfaces.

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32.13, 11:15 am

Differential development of audio-visual integration for saccadic eye movements and manual responses

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The developmental time course of human audio-visual integration is currently unclear. In a simple task eliciting reflexive orienting, infants as young as 8-10 months show reaction time advantages for combined vs. single visual-auditory cues that exceed purely statistical facilitation (Neil et al, Dev Sci 2006). On the other hand, most children do not show similar multisensory advantages until after 7 years when tested with a manual button-pressing task (Barutchu et al, Dev Sci 2009). We propose that these differences may reflect differential development of reflexive orienting, dependent on the superior colliculus, and sensory decision-making, dependent on cortical integration of sensory evidence. To test this our aim is to compare the development of multisensory orienting and button-pressing for the same audio-visual stimuli. In an initial study we recorded eye movements of children aged 4-13 years (N=19) in response to visual (V) flashes, auditory (A) beeps, or both (AV), presented at 20° eccentricity. Subjects first fixated a central cross that disappeared 1300-2300ms before the

stimulus onset in order to avoid cue competition. Overall, mean AV saccadic latencies were significantly shorter than either A or V, and the group as a whole showed a trend towards AV latencies shorter than those predicted by statistical facilitation (Miller, Cog Sci 1982). These results indicate that unlike in button-pressing tasks, children aged 4 years and above can show reaction time advantages consistent with cue integration when tested with a simple saccadic orienting task. We propose that this capacity depends on early-developing subcortical multisensory processing (Wallace & Stein, J Neurosci 1997).

Acknowledgement: UK Economic and Social Research Council Grant RES-062-23-0819

32.14, 11:30 am

Noise and Correlations in Parallel Perceptual Decision Making

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Parallel processing is a basic organization principle of the brain. For perceptual decision making, this suggests that multiple decisions can be made simultaneously. Each decision involves that evidence for an external noisy signal is accumulated over time until a criterion is reached. Critically, evidence accumulation is also subject to internal noise which is, however, difficult to measure directly. Here, we investigated internal noise in parallel perceptual decision making using simple detection tasks. We continuously presented audio-visual noise (Gaussian noise band-pass filtered between 262-330Hz and 200 randomly moving dots, respectively). We asked human participants to indicate the onset of auditory (294Hz tones) and visual signals (50% of the dots moved coherently) and measured response latencies. We first show that latencies in single decision conditions with only the auditory or only the visual signal were negatively correlated to the recent trial history. Second, this knowledge allowed us to predict the exact latency distribution in a dual decision condition, in which both signals were presented simultaneously so that detection of either signal was sufficient for a correct response (OR coupling). By comparing the empirical distribution with the prediction, we concluded that the internal noise level must have been increased in dual decision conditions. Third, we tested this conclusion introducing a new dual decision condition, in which conjunctions of auditory and visual signals were targets (AND coupling). If our noise hypothesis is correct, the latency distribution in the AND condition is fully predicted by the correlation and noise estimates derived in the OR condition. The empirical distribution followed this prediction closely. Thus, separate decisions are flexibly coupled by AND/OR decision gates depending on task demands. Critically, our findings imply that a significant fraction of the internal noise is produced by decision processes themselves, which sets a fundamental capacity limit for parallel perceptual decision making.

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32.15, 11:45 am

Text and speech summate perfectly, despite inefficient feature binding

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To recognize an object, we detect and bind the features it is made of. We also merge information across the senses into a coherent percept of our external environment. In general, how well do we combine information from several sources, be they features, cues, or sensory modalities? Building on the classic efficiency approach (Tanner and Birdsall, 1958), here we introduce a "relative efficiency" paradigm to assess binding. We measure the energy threshold as a function of object extent (a word) or for a combination as opposed to each component alone (audio and visual). Efficient binding has a fixed energy threshold, independent of length or distribution among modalities. Inefficient binding requires more energy as length or number of modalities increases. Our results reveal an amazing dichotomy. Energy is integrated inefficiently within each modality: Observers need more energy to recognize longer words, whether seen or heard. However, text and speech summate perfectly: Observers require the same overall energy, irrespective of its distribution across eye and ear. Thus, to see and hear a word, we inefficiently combine features but efficiently combine streams.

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32.16, 12:00 pm

Striking parallel between Tonotopy in Auditory Cortex and Retinotopy in Visual Cortex: a human fMRI study at 7 Tesla

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In contrast to visual retinotopic mapping with fMRI, auditory tonotopic mapping has not yet provided a clear picture of the human auditory cortex because map details are just below the spatial resolution of standard functional imaging techniques. As a result, the exact number and location of tonotopic maps in the human auditory cortex (including the primary and secondary regions) remains largely unknown. Here, using ultra-high field strength fMRI (7T) with voxel volumes as low as 1.7mm³, we have imaged tonotopic maps in 10 human subjects, and provide the clearest measures of human tonotopy to-date. A phase-mapping approach was used, similar to that commonly used in retinotopic mapping. The results are highly consistent in 20 out of 20 hemispheres and clearly demonstrate that iso-frequency lines run parallel to the long-axis of Heschl's gyrus (settling a long-standing debate about the orientation of the primary maps). Furthermore, the results suggest a striking and previously unknown organizational parallel with early visual cortex. Specifically, the low frequency union of two mirror-symmetric tonotopic maps (border between primary areas A1 and R) is consistently located on the crown of the gyrus, thus bringing common frequency bands on the two maps closer together in space along the sides of the gyrus. A similar pattern is known to exist in the visual cortex, where the unions of mirror-symmetric retinotopic maps (borders between V1 and V2) also occur on a cortical fold thus shortening cortical distances between common retinotopic points on the two maps. This phenomenon in the visual system has been the primary argument for an influential hypothesis (Van Essen 1997) that cortical folds occur as a result of axonal tension between interconnected regions. In summary, our results significantly clarify the organization of human auditory cortex, and also suggest a common pattern with early-visual cortex.

Acknowledgement: Swiss National Science Foundation

32.17, 12:15 pm

Decoding natural sounds in early visual cortex

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Despite early visual cortex being one of the most intensely studied systems in the brain, the majority of processing variance is still unexplained. Here we show that information from hearing is contained in the activity patterns of early visual cortex, in a content-specific manner, in the absence of visual stimulation and despite an orthogonal working memory task. In Exp. 1, subject listened to 3 types of natural sounds while being blindfolded. We successfully decoded the sounds from retinotopically defined early visual cortex BOLD activity (mainly in V2 and V3) using multivariate pattern analysis (a linear support vector machine). To constrain mental imagery, subjects performed an orthogonal working memory task in Exp. 2, again in the absence of visual stimulation. Subjects memorised word lists of animals and objects during natural sound stimulation and performed a delayed match to sample task. Natural sounds were still successfully decoded from early visual cortex activity, despite mental imagery being restricted. These results show that contextual information from the auditory modality is contained in the activity patterns of early visual cortex, possibly to facilitate visual predictions.

Acknowledgement: BBSRC BB/G005044/1

Attention: Neural mechanisms and reward

Sunday, May 8, 10:45 - 12:30 pm

Talk Session, Royal Palm 4-5

Moderator: Yuka Sasaki

32.21, 10:45 am

Superior colliculus inactivation impairs covert selective attention to motion but does not alter gain modulation of motion signals in areas MT and MST

Richard Krauzlis¹(rich@salk.edu), Alexandre Zenon¹; ¹Systems Neurobiology Laboratory, Salk Institute for Biological Studies

Superior colliculus (SC) inactivation causes large deficits in covert selective attention, but the mechanisms are not known. One possibility is that SC inactivation disrupts attention-related mechanisms in sensory areas of cerebral cortex. To test this idea, we recorded neuronal activity in areas MT and MST during a covert attention task involving motion, before and during SC inactivation. A rhesus macaque performed a motion change detection task, which required him to report if the motion direction in a cued patch changed, while ignoring changes in a simultaneously presented foil patch. The two patches were placed at symmetric locations across the fixation point and changes occurred after a variable delay during maintained fixation. The task was to report the change in the cued patch by pressing a button, and make no response if the motion change occurred in the foil patch. We first confirmed that MT and MST neurons had higher firing rates when the cued stimulus, rather than the foil, was placed in their receptive fields, similar to the cue-related gain changes found in previous studies. Next, we used muscimol, a GABA agonist, to focally and reversibly inactivate the SC during the task. Consistent with our previous results, SC inactivation caused a dramatic decrease in the ability of the animal to correctly detect motion changes in the affected visual field, and an increase in the number of erroneous responses to uncued events occurring in the unaffected field. Finally, we recorded MT and MST units before and during SC inactivation, and found that SC inactivation did not alter the cue-related gain modulation in firing rates, even though large deficits in selective attention were observed at the same time. These results suggest that SC activity contributes to covert selective attention by means that are largely independent of gain modulation of sensory signals.

32.22, 11:00 am

On the limits of top-down control of visual selection

Jan Theeuwes¹(J.Theeuwes@psy.vu.nl), Erik van der Burg¹; ¹Vrije Universiteit Amsterdam

Imagine a situation in which two uniquely colored and highly distinguishable objects are present in the visual field. Each time before you start searching, you are told which of the two objects you need to select. For example, on one trial you need to select the red object and on the next trial you need to select the green one. On the face of it, this should be no problem: Everyone expects that people can select the object they are told to select. This intuitive assumption is reinforced by basically all theories on visual search which predict that people can select the object needed for their task. The basic idea is that top-down set can increase the saliency of the relevant feature dimension (in this example: the feature "red" or "green") such that attention is guided to the relevant feature only. Even though all theories predict efficient top-down selection, here we show that selection in a top-down manner is inefficient; people cannot flexibly select the object needed for their task. Observers viewed displays in which two equally salient color singletons were simultaneously present. Before each trial, observers received a word cue (e.g., the word 'red', or 'green') telling them which color singleton to select on the upcoming trial. The results show that selection was not perfect: When searching for the relevant color, observers could not prevent attentional capture by the irrelevant color singleton. Only when the color of the target singleton remained the same from one trial to the next was selection perfect, an effect which is thought to be the result of passive automatic intertrial priming. The present study demonstrates the limits of top-down attentional control.

32.23, 11:15 am

Early involvement of prefrontal cortex in bottom-up visual attention: comparison of neural response times in monkey prefrontal and posterior parietal cortex

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The dorsolateral prefrontal (dlPFC) and posterior parietal cortex (PPC) represent visuospatial information and are both activated during tasks requiring orienting of attention; however, the distinct roles of PFC and PPC in visual bottom-up attention are still controversial. We used three behavioral tasks that orient attention based on bottom-up factors and compared the time course of neuronal activity of area 46 of dlPFC and areas LIP and 7a of PPC. In the first task, monkeys were trained to identify a salient stimulus surrounded by distractor stimuli on the screen (color and location varied randomly from trial to trial) and to release a lever when another stimulus appeared at the same location. Analysis was performed on 222 dlPFC neurons, 104 LIP neurons, and 90 7a neurons with significant responses to visual stimuli. Surprisingly, the average time of target discrimination was earlier in dlPFC neurons (120-130ms) than in LIP neurons (140ms) and 7a neurons (160ms), even though visual response latencies of PPC neurons were no longer than PFC latencies. The results indicate that salient stimuli defined by bottom-up factors are represented first in the activity of prefrontal than parietal neurons in this task. In order to investigate further how the timing of neuronal activity in prefrontal and parietal cortex determines the animals' behavioral responses, monkey's reaction times were tested in the second task by requiring them to release the lever as soon as they found the salient stimulus in an array. We varied the task difficulty by adjusting the color (hue) of distractor stimuli. The average lever releasing time increased as a function of task difficulty. In the third task, monkeys naïve to visual search tasks passively viewed stimulus sets. Neural and behavioral results from these experiments will provide insights into the role of prefrontal and parietal cortex in orienting of bottom-up attention.

Acknowledgement: NIH grant R01 EY16773

32.24, 11:30 am

Detection performance is modulated at a low-theta selection rhythm.

Ayelet Landau¹(ayelet.landau@gmail.com), Pascal Fries¹; ¹Ernst Strüngmann Institute in Cooperation with Max Planck Society

Previous studies have supported the idea that slow brain rhythms are related to behavioral performance (e.g., Busch and VanRullen, 2009). Such findings suggest that the visual environment is sampled rhythmically for processing rather than continuously. In the present study, we investigated fluctuations in attentional performance. We found evidence that accuracy on a detection task followed a slow rhythmic pattern (approximately 5Hz). Participants viewed two drifting gratings presented on either side of a central fixation. The task was to report the appearance of a brief contrast decrement (target) within one of the gratings. Contrast decrements were pre-adjusted to equate performance across individuals. Trials were terminated by participant's response and lasted no longer than 3.8 s. Ten percent of trials contained no target (catch trials). In addition, a peripheral irrelevant probe briefly appeared surrounding one of the gratings. We varied the temporal interval between the target and the irrelevant probe: The target could appear from 750 ms before the irrelevant probe to 1000 ms after the irrelevant probe in steps of 16.7 ms. In addition, probe and target could either appear in the same or in different visual fields. Target-detection rates were analyzed as a function of the target-to-probe interval. The irrelevant probe manipulation was designed to reset performance in time and space, which indeed was achieved. When target and probe shared visual field, target detection was entirely masked. Importantly, after the probe, target detection at the probe side oscillated at 5 Hz. Interestingly, a similar oscillation occurred also for targets opposite to the probe side. The two oscillations were in anti-phase. This is consistent with a selection mechanism that samples one target location at a time in a rhythmic fashion and explores multiple locations in succession.

32.25, 11:45 am

Visual information processing in the absence of pulvinar input

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Pulvinar is the largest thalamic nucleus in primates, having expanded in proportion to neocortex through evolution. Its well-differentiated sub-nuclei have reciprocal connections with different visual cortical areas. Lateral pulvinar (PL) receives input from layer 5 of primary visual cortex (V1) and projects to supragranular layers 1-3 of V1 which, in turn, send outputs to extrastriate ventral visual stream. We studied the effect of PL inactivation on neural activities in supragranular layers of V1 in anesthetized, paralyzed primates (*Otolemur garnettii*, N=3). V1 responses to drifting sinusoidal gratings were recorded using a 100-electrode array implanted in supragranular layers. Muscimol was injected in retinotopically matched region of PL. PL inactivation resulted in an almost complete loss of stimulus-driven activity in 95% of all V1 cells studied (N=164). Despite this overall loss in activity, intriguing changes to the phasic component of the stimulus-driven response were noticeable. Across all orientations, the average instantaneous spike rate of the phasic response to stimulus onset was 4.0 times that of the maintained response before PL inactivation, but decreased to 1.3 after inactivation. Near the preferred orientation, a selective suppression of activity below the maintained response was noticed instead of the phasic increase in activity. This suppression was significant in 95% of units (Rank-Sum, $P < 0.01$). V1 neurons with partially overlapping receptive fields with inactivated PL neurons showed a significant sustained component in their stimulus-driven activity but without the transient phasic component. Sham injection 500 μm above PL obtained no changes in V1 responses. Thus, PL inactivation profoundly affects activities in the "output" layers of V1. Decreased activity and the strong suppression of the phasic component of stimulus-driven response in the "output" layer neurons could be potential mechanisms for gating the flow of information from V1 to the ventral stream and for bottom-up, stimulus-driven modulation of attention and visual salience.

Acknowledgement: NIH EY01778

32.26, 12:00 pm

Using MVPA to dissociate the role of object-centered and eye-centered reference frames in attention

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A wealth of research has addressed the nature and location of retinotopic (eye-centered) maps (in occipital, temporal, parietal and prefrontal cortex), which show egocentric coding of a hemifield or quarterfield of visual space (for review, see Wandell et al, 2007). However, few studies have examined allocentric, non-lateralised reference frames, such as those posited for object-based coordinates, which can be affected by hemispatial neglect (Behrmann and Tipper, 1999). We ran an fMRI study to compare eye-centered (retinotopic) and object-centered (objectotopic) reference frames during an attentional experiment, where participants monitored the motion of a variable number (1 to 4, out of 6) of target gratings (defined by colour) and detected transient changes in their velocity. Three of the gratings were located inside each of two discs at either side of fixation, providing object-based grouping. Multi-Voxel Pattern Analysis (MVPA) dissociated retinotopic and objectotopic spatial coding in eye-centered and object-centered coordinates independently. This revealed extensive hemifield-specific retinotopy in occipital and parietal cortex, but no sign of objectotopy. Furthermore, univariate analyses revealed substantial independence in the load-scaled activity in each hemisphere, consistent with previous behavioural reports (Alvarez and Cavanagh, 2005). The current dissociation suggests that retinotopic reference frames are automatically engaged during attentional monitoring, but remains equivocal regarding objectotopic reference frames. We discuss several possibilities. Perhaps object-based reference frames do not exist and are unnecessary to explain clinical findings (Mozer, 1999). Alternatively, object-based reference frames are only activated by specific task requirements.

Acknowledgement: Medical Research Council

32.27, 12:15 pm

Reward reduces inhibitory control as shown in retrieval-induced forgetting

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While effects of reward on conditioning have been extensively studied, its role in perceptual learning and memory is still unclear. Recently we have shown a case in which task-irrelevant stimuli were learned only if they were paired with reward (Seitz et al., 2009, *Neuron*). This result raises the possibility that reward enhances signals that are usually inhibited. Here, we test this hypothesis by applying Seitz et al. (2009)'s rewarding paradigm to retrieval-induced forgetting (RIF), in which a non-practiced item under the same category as a practiced item is inhibited from being retrieved (Anderson et al., 1994). The current experiment consisted of three phases; encoding, retrieval practice and memory-test phases. In the encoding phase, 91 participants tried to encode category-exemplar pairs (e.g. FRUIT-orange). Then, in the retrieval practice phase, they were presented with a category name and a two-letter word-stem (e.g. FRUIT-or) and were asked to complete an encoded word. When they completed correctly, drops of apple juice were delivered as rewards in the reward condition and a beep sound was presented instead in the control condition. In each trial of the memory-test phase, the participants were asked to report whether or not each exemplar had been presented in the encoding phase. If RIF occurs, in the memory-test phase, the exemplars that were not practiced in the retrieval practice phase under the same category as practiced exemplars are less likely to be retrieved than unpracticed exemplars not under the same category as the practiced exemplars. The results of the memory test indicated that RIF was eliminated in the reward condition, although RIF occurred in the control condition. These results suggest that the reward modulates inhibitory mechanisms of memory. Since the prefrontal cortex and/or hippocampus plays important roles in RIF (Kuhl et al., 2007), reward may modulate inhibitory processing in the area.

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Eye movements: Perisaccadic perception

Sunday, May 8, 8:15 am - 12:15 pm
Royal Palm 6-8, Poster Boards 301 - 310

33.301 Peri-Saccadic Visual Sensitivity while Freely-Viewing Natural Movies

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We now have a relatively good understanding of contrast sensitivity for narrowband gratings in observers who maintain stable fixation. However, in everyday vision, humans make several eye movements per second, and the time-varying input to the visual system comprises a very broad distribution of spatio-temporal frequencies, orientations, and intensities. We used a real-time gaze-contingent display to locally change contrast in high-resolution naturalistic (blu-ray) videos during free viewing. Every video frame was decomposed into its spatial frequency bands on a Laplacian pyramid in less than 1 ms; eye movements were recorded at 1000 Hz and local spatially narrowband contrast modifications in retinal coordinates were applied at the screen refresh rate (120 Hz) and a typical latency of 14-22 ms.

In video watching sessions lasting about 10 minutes and approximately every 2 s, energy in the 1.5-3 cyc/deg band was increased for 600 ms in a 2x2 deg spatio-temporal raised Gaussian windowed patch at one out of four locations, 2 deg away from the point of regard.

The spatio-temporal structure at test locations and the latency between stimulus and saccade onsets were analyzed offline. Localization performance overall was low compared with gratings; was best for stationary eyes and worst when a saccade was initialized c. 500 ms after target onset ("late").

This effect could only be partially explained by differences in stimulus contrast and motion that modulated sensitivity and were correlated with eye movement activity. A second experiment replicated the retinal input of the first experiment by shifting the movie on screen according to the previously recorded gaze, while subjects maintained central fixation. Even though the retinal input was the same, simulated "late" saccades had a less detrimental effect.

Contrast sensitivity is profoundly changed by eye movements and natural contexts and is thus poorly characterized by measurements obtained with traditional methods.

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33.302 Egocentric but not allocentric perceptual distortions from saccadic adaptation

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Saccadic adaptation, the ability to progressively shift the endpoint of a saccade to take into account changes in the location of a visual target [McLaughlin, 1967] also results in visual compression of the adapted region [Bahcall & Kowler, 1999]. More recently, it has been proposed that saccadic adaptation induces a perceptual mislocalization even during fixation, and that this is caused by a distortion of visual space at the adapted location [Zimmermann and Lappe, 2010]. Prompted by this work, we induced saccadic adaptation and measured subjects' pointing movements to the perceived post-saccade target location; we found that subjects could adapt, both inwardly and outwardly and that their motor response data exhibited the expected distortion. We followed this with interleaved top-up saccadic adaptation trials and vernier alignment trials, in which subjects judged the position of a flashed target relative to distant static flankers. There was no consistent change in the perceived alignment of the vernier target relative to the flankers following saccadic adaptation. The mislocalizations from saccadic adaptation therefore do not seem to be in an allocentric representation of space but are more likely confined to motor/egocentric space.

Acknowledgement: NSF, NIH

33.303 The role of surface feature information in object persistence across saccades

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Two broad theories of transsaccadic object persistence and visual stability posit, on the one hand, that object persistence depends on the mapping of spatial pointers assigned to the pre- and post-saccadic objects (e.g., Cavanagh et al., 2010; Pylyshyn, 2000) and, on the other, that object persistence depends on the retention and comparison of object surface features across the saccade (e.g., Currie et al., 2000; Hollingworth et al., 2008). We tested these two hypotheses by probing the role of surface feature information in object persistence across a saccade. On each trial, a saccade target was shifted spatially during the saccade to that object. In previous work (Deubel et al., 1996), perception of shift direction was poor when the post-saccade object could be considered a continuation of the pre-saccade object (no gap condition), leading to updating of the pre-change position of the target object. On the other hand, when object continuity was disrupted by removing the target briefly after the saccade (gap condition), perception of shift direction was highly accurate. In the latter case, the post-saccade target was perceived as a new object, leading to efficient comparison between the pre- and post-saccade locations. Thus, sensitivity to transsaccadic shifts can be used as a measure of object continuity. In the present study, we included additional conditions in which the surface features of the saccade target were changed across the saccade. We replicated the original Deubel et al. findings: Shift detection performance was significantly better in the gap condition than in the no gap condition. Importantly, changing the target object's surface features across the saccade improved sensitivity to position shifts relative to the no gap condition, consistent with the view that transsaccadic memory for object surface features plays an important role in object persistence.

33.304 Saccadic decisions in response to new objects in spatio-topic and retinotopic reference frames

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When making saccadic eye movements, the retinal coordinates of objects are altered, but their spatiotopic (i.e. world) coordinates remain stable. In short sequences of saccades we examined how previous visual stimulation influenced decisions about where to look next. During an initial saccade to the centre of the screen, a test display appeared with two noisy luminance patterns of different contrasts. Participants had to direct their second saccade to the higher contrast pattern. The number of patterns in a preview display shown before the first saccade varied between 0, 2 and 4. When present, the patterns in the preview were of equal contrast. The spatial configuration of the preview and test displays was such that an object could be a retinotopic and spatiotopic onset (experiment 1); a spatiotopic onset, but retinotopic match (experiment 2); a retinotopic onset, but spatiotopic match (experiments 2 and 3); and a retinotopic and spatiotopic match (experiment 3). We assessed choice accuracy as a function of the retinotopic/spatiotopic nature of the patterns. When both retinotopic and spatiotopic onsets were present, participants were split in their preferences: half preferentially responded to new objects in world co-ordinates; half preferentially responded to new objects in retinal co-ordinates. When all objects were spatiotopically stable, all participants preferentially responded to retinotopic onsets. This preference may reflect a saccadic response bias towards locations coded by mechanisms that receive novel stimulation. Such a bias would contribute to directing the eyes towards discontinuities in the retinal image, which could facilitate image segmentation.

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33.305 **Binding of location and color in retinotopic, not spatiotopic, coordinates**

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Our eyes are in constant motion, and therefore, the visual input projected onto the retina is continually changing. This presents a major challenge to our visual system: with each eye movement, objects of behavioral importance stay in the same world-centered (spatiotopic) locations, while the locations relative to our eyes (retinotopic) change. Past research has shown that when attending to a spatiotopic location, attention briefly remains in retinotopic coordinates after an eye movement before transferring to spatiotopic coordinates (Golomb, Chun, & Mazer, 2008 *J.Neurosci.*). Object location is thought to be so important that it is automatically encoded even when trying to remember a non-related aspect of a stimulus (e.g., its identity or color: Tsai & Lavie, 1993, *JEP:HPP*). Our study addresses the question: Do these task-irrelevant location benefits also persist in retinotopic and/or spatiotopic coordinates? Participants fixated on a fixation dot while a colored square was presented in the periphery; the task was to remember the exact color of the square over a short (~1 sec) delay. During the delay, participants made a guided saccade to a different location. A second colored square was then presented, and participants had to report whether or not it was the same exact color. The second square appeared in one of three critical locations: the same spatiotopic location as the sample, the retinotopic location, or a control location. Despite the fact that location was irrelevant to the task, participants were faster and more accurate at judging the color when the test square appeared in the same retinotopic location as the sample square. On the other hand, participants were no more accurate for the spatiotopic compared to the control location. This demonstrates that task-irrelevant location benefits are encoded primarily in retinotopic coordinates, suggesting that feature-location binding also occurs in native retinotopic space.

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33.306 **Breakdown of spatial constancy for head roll but not head translation.**

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Stationary objects are displaced on the retina whenever the eyes or head move but the visual system attempts to correct for the effects of this self-motion to recover spatial coordinates. The accuracy of the compensation can be visualized by moving the target at the time of the saccade or head movement. For example, two dots that are presented at different locations, one before and one after a saccade, are seen to move to within 5% of world coordinates (Cavanagh & Szinte, VSS 2009). We repeat this procedure for two types of head motion: roll around and translation along the visual axis. In the first case, subjects made head rolls of approximately 90° around the visual axis in synchrony with red to green color changes of the fixation spot. Two target dots were presented sequentially, vertically aligned above fixation, one before and one after the head roll. The spatial displacement between the dots was purely vertical whereas the retinal displacement, oriented 85° away from vertical, was almost horizontal. On average, subjects reported a strong oblique component in the perceived motion. In the second case, subjects made large forward and backward translations of the head while fixating and synchronizing their head motions to the red to green color changes of the fixation spot. Two target dots were again presented sequentially above the fixation spot, one before and one after each head translation. The two target dots were displaced horizontally on the screen, but on the retina their displacement was oriented obliquely, 76° away from horizontal. In this case, only small deviations from horizontal were reported. Compensation for head translation therefore appears to be much more accurate than for head roll, implying a difference in the contribution of the otoliths and the semicircular canals to the correction of spatial locations during head movement.

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33.307 **Computational mechanisms of predictive remapping and visual stability**

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Cells in many visual areas are retinotopically organized, i.e. their receptive fields (RFs) are fixed on the retina and thus shift when the eye moves. Thus, their input changes with each eye movement, posing the question of how we construct our subjective experience of a stable world. It has been proposed that predictive remapping could provide a potential solution (Duhamel et al., *Science*, 255, 90-92 1992; Melcher & Colby, *Trends in Cog. Sci.*, 12, 466-473, 2008; Wurtz, *Vis. Res.*, 48, 2070-2089, 2008). Predictive remapping refers to the observation that for some neurons RFs anticipate the eye movement and become responsive to stimuli which are presented in their future receptive field (FRF) already prior to saccade. Recent evidence from investigations in the frontal eye field suggests that the anticipatory updating is brought about by the corollary discharge (CD) to move the eyes (Sommer & Wurtz, *Nature*, 444, 374-377, 2006). However, at present it is unclear how CD could alter the RF profile. Moreover, there exists no clear theory let alone a computational model of how predictive remapping contributes to the subjective experience of visual stability. Based on a realistic systems neuroscience model of area LIP and using CD of eye displacement and proprioceptive eye position as inputs, we show that predictive remapping emerges within a model of coordinate transformation by means of the interaction of feedback and CD. Moreover, we demonstrate the influence of predictive remapping on visual stability as objectified by a suppression of saccadic displacement task (Deubel et al., *Vis Res.* 36, 985-996, 1996). The model predicts that an absent CD signal leads to a bias negative to saccade direction in SSD. Remapping introduces a feedback loop which stabilizes perisaccadic activity and thus leads to the typical increase in displacement detection threshold.

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33.308 **Fidelity of spatial memory across eye movements: Retinotopic memory is more precise than spatiotopic memory**

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Visually-guided behavior requires information about spatiotopic (world-centered) locations, but initial visual input is retinotopic (eye-centered). Does spatiotopic information reside in higher-level, spatiotopically-organized visual maps, or is it continually reconstructed from retinotopic information with each eye movement? Recent work favors the latter option; to a surprising extent, visual processing occurs in native retinotopic space, even in higher-level visual areas (Golomb, Chun, & Mazer, 2008 *J.Neurosci.*; Golomb & Kanwisher, VSS 2010). These findings suggest a counterintuitive hypothesis: despite our conscious experience of an effortlessly stable spatiotopic world and our lifetime of practice with spatiotopic tasks, human behavior might actually be better in retinotopic coordinates than in the more ecologically relevant spatiotopic coordinates. To test this idea, we had subjects perform two sessions of a spatial working memory task: one in which they memorized the spatiotopic (absolute) location of a cue, and another in which they memorized the retinotopic location (relative to the eyes). After a delay - which included 0, 1, or 2 guided saccades - subjects reported the memorized location by moving the mouse to the appropriate place on the screen. The error in distance between their reported location and the true location was taken as a measure of the precision of spatial memory. On trials with no saccades, spatial memory was equally precise during the retinotopic and spatiotopic tasks. However, after an eye movement, subjects were significantly more precise at remembering retinotopic locations than spatiotopic locations. This difference grew with each eye movement, such that spatiotopic memory continued to deteriorate, while retinotopic memory remained largely intact. Thus, while we are capable of spatiotopic memory, it is not as reliable as retinotopic memory, and the loss in fidelity with each update is not an inevitable cost of eye movements, but rather a consequence of converting the information from its native retinotopic coordinates.

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33.309 **Perisaccadic flash mislocalization depends on whether a background stimulus appears or disappears around the time of the flash**

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A perisaccadic target-flash occurring in the dark tends to be mislocalized (e.g., Honda, 1991; Matin, 1976). This phenomenon is often explained as arising from an extraretinal (exR) signal that changes around the time of the saccade. However, Pola (2004, 2007) proposed that such mislocalization is not simply the effect of an exR signal, but is the outcome of flash retinal (R) signal persistence interacting with the exR signal. Besides accounting for perisaccadic mislocalization in the dark, this R-exR model suggests that the features of mislocalization with a background stimulus are a consequence of the R signal interacting with the background as well as the exR signal (Pola, 2010 VSS). The present study is concerned with the model's prediction that there is a difference between perisaccadic mislocalization when a background stimulus appears just after a flash and when the background disappears at the time of the flash. The model shows that, in the first case, the background (relative to the dark) increases the amount of mislocalization in the saccade direction, whereas, in the second case, the background decreases the amount of mislocalization in the saccade direction. These predictions are compared with experimental results of a study with background visible just after a flash (Matin, Matin, Pola & Kowal, 1969), and the findings of a study with background disappearing at the time of a flash (Dassonville, Schlag & Schlag-Rey, 1995). In both situations, the model's response turns out to be essentially the same as the empirical findings. This correspondence between model and data, along with previous results (Pola, 2004, 2007, 2010) shows that the R-exR model is able to account for perisaccadic mislocalization in a wide range of visual circumstances, i.e., in the dark, with sequential stimuli, and with different spatial and temporal features of background events.

33.310 **How perisaccadic spatial distortion affects on crowding effect?**

Zhi-Lei Zhang¹(zhilei_z@berkeley.edu), Christopher Cantor¹, Jian-Liang Tong¹, Clifton Schor¹; ¹School of Optometry, UC Berkeley

The crowding effect is an inability to distinguish a peripheral visual stimulus that is closely surrounded by flankers, even though it is distinguishable without flankers. Two key configurations determine the strength of the crowding effect: eccentricity of the stimulus, and the separation between the stimulus and flankers. We are interested in the stage of visual processing that crowding occurs (i.e. at an early retinal stage or at a later cortical stage). We designed experiments to demonstrate whether head-centric or retinal location/separation determines the crowding effect. A stimulus flashed before saccade onset was perceived away from its physical location (perisaccadic spatial distortion). In the first set of experiments, the same flanker configuration appeared crowded at 5 deg eccentricity but not at fovea. When the stimulus was flashed before saccade onset, flanked stimuli flashed at 5 deg eccentricity underwent crowding, even though it was perceived to be near the fovea. On the other hand, flanked stimuli flashed at fovea remained uncrowded even though the stimulus was perceived to be near 5 deg eccentricity. These results demonstrate the crowding effect depends on the physical retinal location of stimulus, not the perceived location. In the second sets of experiments, we presented the target and flanker sequentially. In our previous study we have shown that two vertically aligned flashes presented sequentially before saccade onset can be perceived as misaligned. In our setting, when the flanked stimuli were presented at 5 deg eccentricity, the perceived separation between the test and flank can be larger than its physical separation on retina. In this case however, the crowding effect appears to be weakened suggesting that the crowding is determined by perceived separation rather than the retinal separation.

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Development: Childhood and infancy

Sunday, May 8, 8:15 am - 12:15 pm

Royal Palm 6-8, Poster Boards 311 - 323

33.311 **Optical Development in Early Childhood: Results From Non-Cycloplegic Autorefraction**

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Purpose: Despite the importance of optics in the development of human vision and visual functioning, few extensive, long-term studies exist on refractive changes during infancy and early childhood. However, with the emergence of portable, held-hand, non-cycloplegic autorefractors, it is now feasible to provide early normative data. Such information is vital to our understanding of optical development and for providing a basis for early vision screening. **Method:** Right eyes from 1325 2- to 6- year old children were attempted twice with the Welch Allyn SureSight autorefractor. Measurements were obtained without cycloplegia. Although the children were volunteers, our sample is likely representative of a general pediatric population as testing was conducted at all daycare centres in the metropolitan region, participation rates were high, and no children were excluded on the basis of ophthalmic, neurological, developmental, or systemic disorders. **Results:** 1251 of the children completed testing in both eyes. Based on their age at the time of testing, children were placed into age groups, each spanning a 6-month period. Results showed that mean spherical refractive error was remarkably consistent across the age span (range = +1.4 to +1.7D), as was variability. However, mean cylindrical refractive error showed a steady decline from 0.74D at 2 years to 0.50D at 6 years. Again, variability and percentile limits were relatively constant across groups. **Conclusions:** These data provide the first extensive normative data on refractive development across the critical preschool period, as measured with the most prominent of the new generation of non-cycloplegic autorefractors. Our results imply that from 2 to 6 years of age, children show progressively less astigmatism, yet remain consistently hyperopic (about + 1.5D) across this age span. However, this hyperopic "plateau" in spherical refractive error may be short-lived, as our previous work with older children (Adams et al., 2004) reveals a significant progression toward myopia after the 7th year of life.

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33.312 **Unlike Adults, Infants' Visual Preferences are Driven by Lower-Level Visual Features**

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What information guides infants' visual preferences? Adult spontaneous visual preferences are largely determined by semantic associations - when asked to indicate preferences for real-world scenes containing shared semantic associations, adults show high agreement in which images are preferred (Vessel & Rubin, 2010). However, when the same adults indicate preferences for abstract images (e.g. fractals) containing no common semantic interpretations, preferences are highly individual. Therefore, adults' shared semantics lead to shared preferences. Infants, however, are unlikely to have developed semantic associations. What drives their preferences, and will they show agreement?

We measured preferences for fourteen 5-month-old infants (age 5.0 ± 0.27 months; 7 girls). During each session, infants viewed a set of 16 real-world or 16 abstract images on a Tobii 1750 eye tracker. On each trial, a pair of images was presented side-by-side for four seconds and the infant's preference was measured by which image the infant fixated longer. Preferences on each trial were entered into a computerized sorting algorithm that minimizes comparisons (Vessel & Rubin, 2010). Overall preference scores for each infant were computed from the paired-comparison data, and these were then compared across infants.

Surprisingly, agreement in preference across infants was high for both real-world and abstract images (0.45 for scenes: $t(44) = 18.4$, $p < 0.0001$; 0.46 for abstract images: $t(44) = 16.1$, $p < 0.0001$). These means are not different ($t(44) = 0.32$, $p = 0.75$), indicating that infants have similar agreement for both types of images.

These data suggest that infants' visual preferences are driven by lower-level visual features (e.g. shape and color), which are present in both abstract and real-world images. The highly individual preferences for abstract images in adults strongly suggests a developmental change in the information used to compute preferences. As children acquire knowledge of semantic associations, these associations come to dominate preference.

33.313 Feature Processing and Illusory Conjunctions in Infants' Long-Term Memory

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Theories of visual information processing and feature integration, along with previous infant research, have indicated that only individual object features, and not the feature relations, are perceptually processed by early visual mechanisms. Previous research from within the memory domain has further suggested that, based on the encoding of features, errors in memory in the form of illusory conjunctions (i.e. miscombination of features from disparate objects) are likely. Considering that research has shown that infants' memory is particularly reliant on features, their recognition mechanisms should be quite susceptible to memory conjunction errors. Using the mobile-conjugate reinforcement paradigm, young infants were trained with mobiles displaying both O's and R's (or P's and Q's) and tested with stimuli that contained a miscombination of those features such as a Q (or an R), or a stimulus that did not contain these features (S). Results revealed that infants miscombined the individual features of the O and R (and P and Q) such that they recognized a Q (and R). Infants discriminated, however, the S mobile. These findings support previous research and the notion that object features encoded in infant long-term memory are likely stored as independent units irrespective of the spatial relations among those features, consequently allowing for the miscombination of features upon retrieval. Interestingly, however, infants discriminated a mobile displaying the same features as in the R but in a different spatial combination, suggesting that infants encoded some spatial characteristic of the individual feature. In sum, the present findings suggest that individual object features, and not the spatial feature relations, have a preferential status in young infants' long-term memory.

33.314 Quick CSF in preverbal infants with forced-choice preferential looking paradigm

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The contrast sensitivity function (CSF) is widely used to estimate individuals' visual capacities with grating spatial frequency. However, the long testing time limits its use in clinical and practical settings. Infants' CSF acquisitions are even more challenging because of their short attention span and inability to understand language. Rapid measurement of CSF (qCSF) based on Bayesian adaptive inference has been applied on adults, and here we examine whether the qCSF is applicable to preverbal infants with a preferential looking paradigm.

Infants sat facing a CRT monitor. An image for attention attraction was displayed at the center of the screen at the beginning of each trial, followed by an 8.72 degree static sinusoidal grating presented on either the left or right side of the monitor together with a tone. Infants' eye movements were monitored by a camera, and projected to another screen from which two coders made their judgments as to which side infants gazed. The contrasts and spatial frequencies (from 0.11 - 7.73 cpd) of gratings were estimated trial-by-trial to maximize the efficiency of predicting a CSF by Bayesian inference.

Only results with above 70% inter coder rating consistency were included. Sixty-six infants ranging from 3- to 10-months-old met this criterion. Each predicted CSF was defined by four parameters, which were compared with previous infant CSF results. Our CSF peak estimates are consistent with previous studies, only qCSF enabled finer-scaled estimations and shorter testing time - each CSF was derived from an average of 35 trials. This is a marked improvement over previous studies that required multiple visits and a minimum of 30-50 trials for a single threshold estimation. Our results show that qCSF is an efficient method that can be combined with preferential looking paradigm in obtaining a reliable CSF in preverbal infants.

33.315 Four-month-old infants exhibit lightness constancy

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Perceptual constancies allow us to perceive properties of the distal environment despite variations in proximal stimulation. For example, adults are able to perceive the reflectance of an object despite changes in illumination; i.e., they are capable of lightness constancy. We investigated whether 4-month-old infants (n=17) show evidence of lightness constancy. Infants viewed two faces through an aperture in a lighted enclosure. To measure a natural preference for a dark or light face, infants were presented with two pre-test trials under either low (group 1) or high (group 2) illumination. Infants were then habituated to either two white faces under low illumination (group 2) or two dark grey faces under high illumination (group 1). The luminance values for the faces during habituation were matched for the two groups. In test trials, infants were again shown the white face and the gray face under the same illumination levels presented in the pretest trials. Therefore, after habituation, one of the two faces was novel in reflectance while the other was novel in luminance. For each infant, a novelty preference was calculated by dividing the amount of time spent looking at the face that was novel in reflectance by the total looking time. Following habituation, infants showed a 58% preference for the face with the novel reflectance (p = 0.015). We also calculated the change in looking preference between the pre-test trials and post-test trials. There was a 12% greater preference for the novel reflectance in the post-test trials than the pre-test trials (p=0.007). These results indicate that 4-month-old infants recognize an object's reflectance across changes in luminance. This indicates a degree of lightness constancy by 4 months of age. Our findings are consistent with those of Chien, Bronson-Castain, Palmer, & Teller (2006), the only previous study on lightness constancy in infants.

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33.316 Denoising developmental fMRI data: Removal of structured noise from a passive-viewing task differentially impacts children and adults

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When collecting functional magnetic resonance imaging (fMRI) data across multiple populations, inherent differences in physiological signals can distort comparisons of effects. For example, children differ from adults with respect to breathing and heart rates, which could differentially affect the blood oxygenation level dependent (BOLD) response. Furthermore, known differences in task-negative or default mode processing may affect comparisons of task-positive activity. We collected fMRI data during a blocked-design task involving passive viewing of faces, diverse objects, and scrambled stimuli, administered to over 70 participants ranging in age from 6 to 34 years old. We fine-tuned a processing methodology to meet the specific challenges of comparing data across age-groups by removing structured noise from fMRI data prior to standard individual regression analyses. We first applied independent components analysis (ICA) to decompose BOLD data into spatially independent patterns of activation, each with a variable timecourse. We then entered the timeseries of the resulting independent components (ICs) as multiple regressors against timeseries data extracted from regions of interest (ROIs) placed at known sites of physiological distortion. ICs that were significant predictors of any physiological ROI timeseries were excluded from the subsequent reconstruction of BOLD data, except those that showed a significant correlation ($r > 0.2$) with a gamma function modeling the task-related signal. Additionally, we identified ICs that were significantly anticorrelated ($r < -0.2$) with the task gamma function on the assumption that these components reflected default mode activity. Separate reconstruction of only these task-negative components verified that these signal sources involved regions known to be engaged in resting states, such as medial ventral prefrontal cortex, posterior cingulate, and lateral parietal cortex. Interestingly, however, removal of these task-negative components impacted the assessment of denoised whole-brain task-positive activity differently for children relative to adults. This finding has important implications for comparing task effects across development.

Acknowledgement: NIH 5R01HD060595-02

33.317 Development of visual motion processing: Latency of direction-specific VEP in infants compared to adults

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Pattern-reversal (PR) VEPs are present in newborns, while direction-reversal (DR) VEPs emerge around age 9-11 weeks age (Wattam-Bell, Vis Res, 1991). Comparing the latency of these responses can reveal the emerging properties of direction-selective mechanisms in infants' visual cortex.

DR and PR-VEPs were tested in 46 adults at 1-4 reversal/sec (r/s). DR mean latency was 90 ms, close to the P100 latency for PR responses. However, 35% of participants showed a dominant early peak of 60ms (Braddick et al, VSS 2009). For 38 infants aged 4-54 weeks, 76% showed dominant early peaks (average latency 84 ms) in addition to the later peak of 145 ms. The early peak suggests a fast motion pathway, possibly bypassing V1, which may precede the slower pathway in development.

Latency measures were also calculated from the slopes of phase vs temporal frequency plots (adults: 1-16 r/s, infants: 1-8 r/s). Adults' calculated latency for PR was similar to the transient peak latency. However, the calculated DR latency was approximately double that for the transient peak, presumably reflecting extended cortical processing beyond the initial directional response.

For both stimuli, infants' calculated latency shows a delayed developmental course compared to the transient peak latency. Infants reach adult PR latency values by 15 weeks, but for DR only by 50 weeks. However, the calculated latencies for both PR and DR asymptote to adult values around 35 weeks, suggesting different developmental processes determining the initial peak and the time required for later cortical processing.

In summary, peak latency for motion reflects two pathways, possibly one through V1 and another direct to MT. Even though initial latencies were similar for contrast and motion, the subsequent cortical processing results in a longer calculated latency for motion. This difference also results in separate developmental trajectories.

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33.318 The development of sensitivity to the direction of motion

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Other than one study of infants (Banton et al., 2001), nothing is known about the development of sensitivity to motion direction. Here we investigated sensitivity to small deviations in the direction of motion in 5-year-olds, 7-year-olds, and adults (18-22 years; n=20/group). Stimuli consisted of black dots (diameter = 2.5 or 10 min) moving coherently at 4.16 or 8.65 deg/s against a grey background. The task on each 1s trial was to indicate whether the dots moved to the left or right of a white vertical reference line. We used a 3-down, 1-up staircase to measure the minimum direction deviation that could be discriminated from vertical. Thresholds were based on the mean of two runs for each of the four dot size/speed conditions. There was a significant 3-way interaction between age, speed, and dot size (p < 0.01). Subsequent ANOVAs at each age revealed lower thresholds for the faster than the slower speed in both 7-year-olds (slower, M = 4.7°; faster, M = 2.5°) and adults (slower, M = 6.6°; faster, M = 1.8°) (ps < 0.01). This comparison was marginally significant in 5-year-olds (slower, M = 10.1°; faster, M = 6.9°; p = 0.054). Thresholds were comparable for the two dot sizes at 5 years (smaller, M = 8.4°; larger, M = 8.6°) and 7 years (smaller, M = 3.5°; larger, M = 3.6°). Surprisingly, in adults, thresholds were worse for larger than for smaller dots at the slower speed (small = 3.2°; large = 10.3°, p < 0.01) but not the faster speed (small = 1.6°; large = 2.0°). Poor performance for large, slowly moving stimuli in adults, but not 7-year-olds, may reflect the onset of inhibitory mechanisms after 7 years of age (e.g., Tadin et al., 2003).

Acknowledgement: CIHR

33.319 Depth from motion parallax in infancy: The role of smooth pursuit and ocular following response eye movements

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Previously we showed a developmental relationship between depth from motion parallax (MP) and smooth pursuit (SP) eye movements in infancy (Nawrot, Nawrot & Yonas, 2010; Nawrot, Mayo, & Nawrot, 2009). In infants, as in adults, depth from MP requires SP with mature gain (eye velocity/target velocity). Infants with relatively low SP gain failed to discriminate depth-sign in an MP task but those with higher gains succeeded. In the current study we further investigate the developmental link between motion, eye movements, and depth through ocular following response eye movements (OFR). OFR are visually driven, short-latency, slow eye movements assisting to stabilize gaze during observer translation (Miles, 1998; Kawano, 1999). Importantly, the OFR is depth-selective, stabilizing one depth-plane on the retina (Busetini et al, 1996). Therefore we might expect to find a relationship in the development of OFR, SP, and depth from MP. We presented 12-20 week-old infants with three tasks: A depth from MP task; a SP task; and a translating pattern OFR task. The MP and SP stimulus and procedure are identical to previous research. The OFR task included eight 0.5 sec trials in which a grating pattern translated leftwards or rightwards at 25 d/s. Saccadic enhancement of the OFR was attempted by triggering pattern translation following the infant's saccade to the center of the display. Eye movements were recorded using a Tobii X120 eye tracker. Results suggest a relationship between OFR and depth from MP across this age range. Infants who discriminated depth from MP also showed an ocular following response in both leftwards and rightward directions, while infants who failed the MP task generally failed to show the OFR. We plan to compare results from all three tasks to see whether age or eye movement maturity type is a better predictor of depth perception from MP.

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33.320 Infants' ability to perceive depth produced by vertical disparity

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Horizontal binocular disparity, the horizontal difference of the retinal images in our two eyes, is widely known to produce depth perception. Vertical disparity with an appropriate pattern has also been shown to produce the perception of depth (Ogle 1952, Howard & Kaneko 1995, Backus, Banks van Ee & Crowell 1999, Ito 2005). In the developmental studies, infants aged over 4 months were shown to perceive depth from horizontal disparity (Fox & Aslin 1980, Held, Birch & Gwiazda, 1980). However, infants' ability to perceive depth from vertical disparity has not been clear. This study examined whether infants aged 20 to 27 weeks could detect vertical disparity for the perception of depth as well as horizontal disparity using a preferential looking method. Our stimuli consisted of an oblique line and random-dot background, and uniform vertical disparity was added into the background only. When observing the stimulus, the line is perceived to separate in depth from the background for adults. The stimulus was presented together with a comparison stimulus with zero disparity side by side. Infants are known to prefer the displays with difference in depth to the displays without such three-dimensional difference (Fantz, 1963). If infants showed a preference of the stimulus with vertical disparity to the stimulus without such a disparity, we would conclude that infants could perceive depth from the vertical disparity. As a result, the significant preference for the stimulus with vertical disparity relative to the stimulus with zero disparity was observed. Our results showed the first clear evidence of the infants' ability to detect vertical disparity for the perception of depth.

Acknowledgement: This study was supported by Grants-in-Aid for scientific research (No. 20539004 to Aki Tsuruhara, No. 21243041 to Masami K. Yamaguchi) from Japan Society for the Promotion of Science (JSPS).

33.321 **Developmental trends in detection threshold for looming objects**

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Detection and sensitivity to optical expansion is critical for collision avoidance and survival. Adult sensitivity to looming and motion in depth has been well documented under strict psychophysical conditions (e.g., Regan & Beverley, 1979). Much less is known about perceptual thresholds for looming in complex scenes, and there has been no investigation of developmental decrements in perceptual ability, which may explain in part children's overrepresentation in road traffic casualties. Looming thresholds for children (n = 111) and adults (n = 27) were measured using adaptive (best-PEST) psychophysical procedures to determine sensitivity to looming in foveal or extra-foveal vision (4.25o eccentricity). A photo-realistic image of a car was viewed monocularly against a static road scene background for 200ms. Observers were required to determine whether the car expanded or not. The car image changed in size and virtual distance to simulate approach at different speeds, with time-to-passage fixed at 5s (sufficient time to cross the road). Images were automatically rescaled according to viewing distance so that visual angles were equivalent to those experienced at the roadside. Results show clear developmental trends in looming thresholds. Younger children (6-9yrs) were less sensitive to optical expansion than older children (10-11yrs) and adults when the image expanded isotropically in foveal or extra-foveal vision, and as well as when it expanded with additional lateral image translation (1o scene displacement scaled with distance) in foveal vision, but not extra-foveal vision. Conversion of looming thresholds into vehicle speeds revealed that children are unable to reliably detect cars approaching 5s away at speeds in excess of 25mph if they do not fixate directly on the car, or are in motion when looking down the road. Our study is the first to provide evidence that the neural mechanisms for detection of looming are not fully developed until adulthood.

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33.322 **Six- to 12-month-old infants use emotional response, agent identity, and motion cues in associated learning of social events**

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Studies have demonstrated that infants as young as 3 months old can distinguish between events containing prosocial and anti-social implications in theater play (Hamlin et al., 2007; 2010). However, the way infants are able to do so is still not fully understood. Here we study the roles of emotional responses, agent identity, and motion in animated social interactions among 6-to-12-month-old infants.

Our Experiment 1 tested whether emotional response enhances infants' differentiation between characters in standardized prosocial and antisocial events. At the habituation stage, twenty-seven 6-to-12-month-old infants watched events depicting a climber being helped or hindered to climb up a hill by another character. These events evoked the climber's associated emotional expressions (laughing after being helped or crying after being hindered). In the test stage, the infants viewed two test events with new contexts – the laughing (or crying) climber approached the character who had previously either helped him climb up (consistent with the habituation), or hindered him (inconsistent with habituation). Infants looked significantly longer at the consistent condition, demonstrating that they associated differential emotional responses to the social events, and could apply this knowledge to new contexts.

Experiment 2 was conducted to determine what association was learned. Infants might have used the character (who) or the action (what) or the combination of both (who did what) to distinguish events in Experiment 1. We habituated twenty-eight 10-to-12-month-old infants with the same helping/hindering events. Afterwards, novel events defined by: (1) a new character, or (2) a new motion direction, or (3) a new character with a new motion are presented in the test stage. The looking time significantly recovered from the last habituation trial in all three conditions.

Our results suggest that emotional responses enhance infants' associated learning in social context, and both agent identity and motion direction are acquired during learning.

33.323 **Development of visual sensitivity for topological versus geometric properties in early infancy**

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Background: Several lines of evidence from adult psychophysics, brain imaging data, and honeybee's behavior have supported the notion that topological properties are the primitives of visual representation (Chen, 1982). However, the developmental origin of the sensitivity to topological properties in infancy has not been explored. Thus, the present study aims to explore 2- to 6- month old infants' visual sensitivity to topological versus geometric properties

Methods: The forced-choice novelty preference technique (FNP) was used to test infant's perceptual discriminability. Two discrimination tasks and one generalization task were adopted. A disk and a ring were used in the topologically different condition (but geometrically equivalent), while a disk and a triangle were used in the geometrically different condition (but topologically equivalent). In the generalization task, infants were first familiarized with a pair of identical disks, and then were tested with two novel figures in the test phase in which one was topologically different (a ring) and the other was geometrically different (a triangle).

Results: Our results showed that in the discrimination tasks, 2- to 6-mo-old infants could reliably discriminate figures based on topological difference, but were unable to discriminate figures based on geometric difference. In the generalization task, infants reliably looked more at the "ring" pattern in the test phase, suggesting that the ring appeared to be perceptually more "different" to the infants than the triangle. Further analysis on age versus novelty score revealed two distinct developmental trends. Infants seem to be readily sensitive to topological differences as young as 7 weeks old, while their ability to discriminate geometrical differences significantly improves between 12- and 26- weeks old. In conclusion, our finding suggested that the ability to process topological properties seems to be present and functioning very early in life.

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Development: Amblyopia

Sunday, May 8, 8:15 am - 12:15 pm

Royal Palm 6-8, Poster Boards 324 - 332

33.324 **Cortical thickening of early visual areas in early monocular enucleation**

Krista Kelly¹(kkelly@yorku.ca), Kevin DeSimone¹, Keith Schneider¹, Jennifer Steeves¹;
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Early monocular deprivation from amblyopia results in a cortical thinning of vision-related regions including lingual, pericalcarine, cuneus, and lateral occipital areas (Du et al., 2009). In contrast, congenitally blind individuals show cortical thickening of some vision-related and oculomotor cortices but thinning of higher-order visual areas (Park et al., 2009). We investigated cortical thickness in vision-related regions of individuals who have experienced a very different form of early visual deprivation – monocular enucleation (surgical removal of one eye). Cortical thickness was analyzed from structural MRI images by determining the distance between the pial and white matter borders. Individuals who have had one eye enucleated (n = 6) early in life were compared to binocular controls (n = 11). Monocular enucleation resulted in significant thickening of cortical regions associated with low-level visual processing (cuneus), basic visual motion perception (middle temporal gyrus), and oculomotor function (posterior cingulate gyrus). In contrast, monocular enucleation resulted in significant thinning of higher-order visual areas (parahippocampal and lateral occipital gyri). These findings are consistent with behavioural data showing intact low-level spatial vision but deficient higher-order spatial vision in these individuals. While decreased cortical thickness in higher-order visual areas is consistent with amblyopia data, increased cortical thickness in early visual and oculomotor regions is not. Instead, our results are consistent with data from the congenitally blind. The complete disruption of visual input following monocular enucleation appears to promote reorganization in lower-

level visual areas but atrophy in higher-level visual areas. Together with previous research, these results suggest that deprivation from monocular enucleation and amblyopia have different effects on the visual system.

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33.325 Is tonic vergence protective against strabismus during development?

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Young children have increased accommodative demand due to their typically hyperopic refractive error, while they have reduced vergence demand relative to adults, due to their decreased interpupillary distance. The neural coupling of accommodation and vergence implies that young children may experience an apparent cue conflict for stable accommodative and vergence responses (Bharadwaj & Candy, 2009). Some children develop strabismus, potentially resulting from this conflict (Parks, 1958). How most children are able to avoid strabismus is poorly understood. The purpose of this study was to determine whether tonic adaptation of vergence might protect young children from this conflict by reducing the impact of the neural coupling.

Participants were 3- to 10-year-old typically-developing children and adults, who watched a video at a 33cm viewing distance. They initially viewed it monocularly to determine their baseline heterophoria (with a near IR filter and MCS PowerRefractor, 25Hz). They then watched the video binocularly for 5 or 60 sec, after which their alignment with the filter was measured again to determine the time constant over which they returned to their baseline heterophoria (Schor & Horner, 1989).

The mean phoria at the task distance in adults was 4.4 pd (+/- 2.9) exophoria and in children was 3.5 pd (+/-3.9) exophoria (p=0.60). For these tasks the mean time constants only differed by 1.5sec (p=0.40) (after 5sec viewing) and 1.8sec (p=0.54) (after 60sec viewing) between the adults and children. Thus the balance of tonic adaptation and phasic activity appear similar for children and adults for these tasks.

Given that tonic vergence is active in adults (Schor, 1979), the fact that the data from children were comparable to adults' indicates that tonic vergence could play a role in achieving alignment during development.

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33.326 Links between acuity, crowding and binocularity in children with and without amblyopia

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Amblyopia, the most common cause of childhood visual impairment, is defined by interocular acuity differences, with additional deficits in binocularity/stereo-acuity and elevated foveal crowding (poorer recognition in cluttered visual environments). To better understand amblyopia and the relationship between acuity, crowding and binocularity more generally, we examined each of these performance measures in both amblyopic and unaffected children.

Children, aged 5-8 (n=72), were classified into four groups: controls and those with strabismic, anisometropic, or mixed strabismic/anisometropic amblyopia. We developed a novel videogame-based task with a Landolt-C target modified to resemble Pac-Man. Children indicated target orientation by reporting which of four ghosts (on the screen edges) Pac-Man was facing. Threshold-size (acuity) was measured first, using a modified staircase. Contrast detection and foveal crowding were then measured using target-sizes 3x this threshold. Crowding was quantified as the minimum separation between the target and ghost-flankers required for accurate target-orientation identification. Stereo-acuity was measured using random-dot stereogram ghosts.

While unaffected children generally had equal acuity in each eye, amblyopic children displayed significant interocular acuity differences. The largest interocular differences for crowding were evident in the strabismic and mixed amblyopic groups, though some foveal crowding occurred in both eyes of all children. Despite this variation in range, interocular crowding differences correlated significantly with interocular acuity differences for all groups. Similarly, reduced/absent stereo-acuity was most common with

strabismic and mixed amblyopia, though cases occurred in all groups. In all cases, stereo-blindness was further associated with large interocular differences in both acuity and crowding.

Our results demonstrate that interocular acuity differences correlate with both crowding and reduced stereo-vision, not only for strabismic amblyopia, but also for anisometropic amblyopia and unaffected children where these differences are lower. These findings place amblyopic deficits on a continuum with normal visual development, with important implications for recently proposed "binocular" therapies of amblyopia.

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33.327 Temporal Dynamics of Binocular Rivalry in Normal and Amblyopic Vision

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Although the fellow eye dominates strongly in unilateral amblyopia, how the two eyes interact in binocular vision is largely unknown. Here we investigated the relative contributions of the amblyopic and fellow eyes in a binocular rivalry paradigm. We presented two orthogonal gratings of identical spatial profiles to the two eyes dichoptically, one to the fellow eye at fixed base contrast levels and the other to the amblyopic eye with proportional contrasts, and measured the time-course of binocular rivalry. The same procedure was applied to normal subjects. Five adults with unilateral anisometropic amblyopia and four normals participated. The phase-duration distributions were fitted with gamma functions (Mamassian & Goutcher, 2005). For normal subjects, images in the two eyes fused 17% of the time; increasing contrast in the right eye increased its dominance duration and decreased that of the left eye. The two eyes had approximately equal dominance time when the gratings in the two eyes were of equal contrast. For amblyopes, images in the two eyes fused 27% of the time; the amblyopic eye dominated about 31% of the total rivalry time when the amblyopic/fellow-eye contrast ratio was 1.0, about 50% when it was 3.0, and 68% when it was 5.6. Gamma functions with a single shape parameter but different scale parameters provided excellent descriptions of the phase duration distributions within each group. The shape parameter in the amblyopic group was about half that of the normal group, indicating a less variable switching dynamics in amblyopic vision, although the scale parameters of the two groups were comparable. In summary, the amblyopic eye needed much higher contrast to become dominant, was fused more with the fellow eye, and had comparable alternation rate but with less variance in phase duration. Possible models with interocular inhibition and stochastic processes will be discussed.

Acknowledgement: Supported by NEI, Natural Science Foundation of China.

33.328 The Effect of Early Visual Deprivation on Sensitivity to Orientation in First- and Second-order Patterns

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We examined the effect of early visual deprivation on the development of sensitivity to orientation in 11 patients treated for bilateral congenital cataract (mean duration of deprivation = 107 days; range: 11-196) and 11 patients treated for unilateral congenital cataract (mean duration of deprivation = 109 days; range: 7-245). Patients were 6-30 years old at the time of the test. Each subject judged the orientation of supra-threshold first-order (luminance-modulated) and second-order (contrast modulated) 1 c/deg sinusoidal gratings that were matched in space-average luminance and were created using static binary random noise. First-order stripes without noise were included as a control. The task on each trial was to judge whether the stripes were tilted to the left or right of vertical. Over trials, the orientation of the stripes was varied according to a PEST staircase (Harvey, 1997) that terminated after it reached a threshold at 82% correct with 95% confidence. Patients' thresholds were converted to z-scores by comparison to the appropriate age-matched control group. For first-order stripes, both groups of patients performed normally with and without added noise (ps > 0.10). For second-order stripes, all 11 patients treated for bilateral cataract had negative z-scores and the mean was significantly below zero (t(10) = -3.564, p < 0.01), but 3 of the 11 patients had z-scores less than -3. The deficits for second-order stripes were not correlated with acuity nor age at test in either patient group (ps > 0.20). The results suggest that second-order

processing is more vulnerable than first-order processing to the effects of early visual deprivation, perhaps because it involves additional processing (Chubb & Sperling, 1988); input through a non-deprived eye may decrease the vulnerability.

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33.329 Prolonged periods of binocular stimulation can provide an effective treatment in childhood amblyopia

Anita Simmers¹(anita.simmers@gcu.ac.uk), Pamela Knox¹, Lyle Gray¹; ¹Department of Vision Sciences, Glasgow Caledonian University, Glasgow, UK

The observation that recovery of visual function in amblyopia is contingent on even brief periods of correlated binocular vision suggests that amblyopia is intrinsically a binocular problem. This has profound implications for the treatment of human amblyopia. An alternative approach to treatment should aim to improve binocularity in addition to monocular visual acuity of the amblyopic eye. Global motion detection using a dichoptic stimulation paradigm was employed to measure the extent of binocular interaction; signal dots were presented to the amblyopic eye while the contrast of the noise dots in the fellow eye was varied. Children then played a simple computer game 'Tetris'. In the game the falling blocks forming each pattern were presented to one eye and the stationary blocks to the other eye. Previously measured contrast thresholds were used to match the visibility of the blocks in each eye. This arrangement forces the subject to use both eyes to perform the task, whilst minimizing inter-ocular suppression. The children played the game for 1 hour each session with five sessions over the course of a week. Correlations between binocular vision status, degree and type of amblyopia and the dichoptic contrast imbalance for binocular interactions were determined. Overall, the magnitude of the contrast imbalance for binocular summation was found to reduce significantly over the treatment period, concurrent with improvements in traditional logMAR acuity. Interestingly, under natural viewing conditions the improvement in contrast imbalance was reflected in a strengthening of binocularity and the establishment of measurable stereopsis. These results verify the feasibility of the recovery of binocularity in amblyopic children. It can be hypothesized that patients who do not respond to existing treatments and/or show regression in visual function, may obtain an improved and more stable visual outcome with this binocular approach to treatment.

Acknowledgement: Chief Scientists Office, Scotland (AJS) Visual Research Trust (AJS)

33.330 Examination of Anti-Suppression Therapy for Amblyopia

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Amblyopia, a developmental disorder associated with abnormal early visual experience, is defined by a deficit in visual acuity in the amblyopic eye (AE) which cannot be optically corrected. Although some research on amblyopes suggested visual information from the eyes is not combined, a growing body of studies report that binocular mechanisms are intact, but suppressed. Using dichoptic presentation of stimuli of relatively high and low contrasts to AE and non-AE, respectively, Hess et al. (2010, Optometry & Vision Science) demonstrated that binocular perceptual training can reduce suppression from the non-AE and improve visual acuity and stereoacuity. We examined the influence of binocular perceptual learning on the visual acuity, crowding, stereovision, binocular motion coherence thresholds, and binocular integration in five individuals with severe amblyopia. Binocular integration was measured as the contrast at which noise dots presented to the non-AE influenced the perception of the direction of motion of the signal dots in the AE. Initially, participants demonstrated visual acuity in the AE greater than 1.0 logMAR and nonmeasurable stereoacuity. Whereas 2 participants demonstrated suppression on the Worth 4-dot test, 4 participants evidenced suppression on the binocular integration task. After training on the binocular integration task for 20 to 24 hours, all participants reported better vision and increased ability to focus with the AE, which were supported by better visual acuity ($t(4)=14.3$, $p<0.05$) and less crowding ($t(4)=2.8$, $p<0.05$). In contrast, neither stereoacuity measured on the Randot tests nor suppression measured on the Worth 4-dot test improved. The influence of binocular perceptual training on binocular motion coher-

ence thresholds and binocular integration evidenced individual variation. Our data are consistent with those of previous studies indicating that perceptual training can benefit adult amblyopes' visual experience.

Acknowledgement: NSERC Discovery Grant to PMP

33.331 Quantitative measurement of interocular suppression in children with amblyopia

Sathyasri Narasimhan¹(sathyasri_narasimhan@yahoo.co.in), Emily Harrison¹, Deborah Giaschi¹; ¹Department of Ophthalmology and Visual Sciences, Faculty of Medicine, University of British Columbia

Previously it has been shown that intensive training aimed at reducing interocular suppression leads to improvement in amblyopic eye acuity as well as binocular vision in adults with strabismic amblyopia (Hess et al., 2010). In the current study we explored the possibility of using this approach to measure interocular suppression in children with amblyopia. We compared children (8-12 years old) with unilateral anisometropic and/or strabismic amblyopia to age-matched control children with normal visual acuity and no ocular pathology. Visual acuity was measured using the Regan high contrast chart; stereopsis was evaluated using the Randot preschool and the Randot circles test. Motion coherence thresholds for left-right direction discrimination were determined using a binocular global motion stimulus presented with virtual reality goggles (eMagin). The proportion of signal dots among noise dots was varied with a staircase procedure. In dichoptic viewing, high contrast signal dots were presented to the amblyopic eye (one eye of control subjects) while low contrast noise dots were presented to the fellow eye (the other eye of control subjects) at the motion coherence threshold. The contrast of the noise dots was increased until performance reached chance levels. Higher contrast thresholds indicated less interocular suppression. Regardless of their stereo acuity, all children in the amblyopic group exhibited some degree of binocular function on the dichoptic motion task. The amount of interocular suppression was high in the strabismic group and low in the anisometropic group indicating that interocular suppression is more potent in strabismic than in anisometropic amblyopia (Harad and Hess, 1992). We have shown that the Hess et al stimuli can be used to measure both interocular suppression and residual binocular function in children with amblyopia. Interocular suppression is an established mechanism for visual loss in strabismic amblyopia; our results suggest it is less of a problem in anisometropic amblyopia.

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33.332 Improving the screening of children for amblyopia

Denis Pelli¹(denis.pelli@nyu.edu), Shuang Song², Dennis Levi²; ¹Psychology and Neural Science, New York University, ²School of Optometry, UC Berkeley

Large trials in Israel and Sweden have demonstrated a very favorable cost-benefit ratio in screening children for amblyopia. Song, Levi, and Pelli (in prep.) find that the foveal vision of strabismic amblyopes is well-modeled by the crowding of normal peripheral vision. That finding on adults indicates that two improvements to existing charts would greatly increase their diagnostic sensitivity to strabismic amblyopia in children, with no loss of specificity. First, the flankers should be letter-like, not bars. Second, the flankers should be closer to the target letter, i.e. more tightly spaced. Atkinson's Cambridge Crowding Cards are exemplary in this regard, having the tightest spacing of all commercially available tests. These principles will be proven by demonstration at the presentation.

Acknowledgement: NIH R01-EY04432 to DGP and R01-EY01728 to DML.

Face perception: Expression and emotion

Sunday, May 8, 8:15 am - 12:15 pm

Orchid Ballroom, Poster Boards 401 - 410

33.401 Aftereffects for contrast-negated faces in gender and emotion categorization

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Bruce and Young's (1986) model of face recognition proposed that facial identity and emotional expression are processed independently. Yet, it has been argued that certain processes such as the perception of configural information are an important part of both face recognition and expression perception that can be marred by contrast negation and inversion (Calder

& Jansen, 2005; Hole, George, & Dunsmore, 1999). Previously we reported a dichotomy between the effect of contrast-negation on gender and emotion discrimination, with a devastating effect of contrast-negation on gender judgments. To investigate the neural basis of this dichotomy, we used an adaptation paradigm to measure aftereffects from contrast-negated gender and emotion adaptation. If facial expression processing and gender discrimination are fully separated, then in accordance with our previous results adaptation to a contrast-negated angry male face would produce an aftereffect in positive contrast emotion categorization but not positive contrast gender categorization. However, if emotion and gender discrimination share in their initial perceptual processing and the effect of contrast-negation occurs later, then adaptation to a contrast-negated face would produce equal aftereffects in emotion and gender categorization in the positive testing face. We found significant aftereffects for contrast-negated face adaptation in both gender and emotion categorization (Exp 1), with no significant difference in effect size between gender and emotion. Moreover, this pattern of results was identical to that obtained with inverted face adaptation (Exp 2). In both experiments, adaptation to the original angry male face produced a larger aftereffect than contrast-negated or inverted face adaptation. Contrast negation destructs the otherwise highly stable ordinal luminance relations between a few face regions (Gilad, Meng, & Sinha, 2009). In combination with our previously reported findings, our results suggest that these luminance relations are crucial for gender discrimination at the stage when facial expression processing and facial identity are separated.

33.402 Happy or Sad? Context Does Not Influence Four-Year-Olds' Perception of Happy and Sad Facial Expressions

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Adults' perception of facial displays of emotion is influenced by context; they make more errors and take longer to respond when the emotion displayed by the face (e.g., fear) is incongruent with the emotion displayed by the body (e.g., anger) (Meeren et al., 2005). This congruency effect is larger when emotions are similar (Aviezer et al., 2008). Previously, we reported that, like adults, 8-year-olds show congruency effects for sad/fearful facial expressions, but not sad/happy facial expressions, perhaps because happy and sad expressions differ in valence and intensity whereas fearful and sad expressions differ only in intensity (Widen & Russell, 2008). Additionally, happy and sad expressions share fewer physical characteristics than fearful and sad expressions (Aviezer et al., 2008). Because even infants and preschool children are sensitive to emotional valence (Widen & Russell, 2008) we hypothesized that pre-school children would not show congruency effects for happy and sad facial expressions. Four-year-old participants (n = 12) helped a puppet sort faces into one of two houses (a happy or sad house); faces were presented in isolation, and on congruent/incongruent bodies. They showed no effect of congruency, $p > .20$, despite sorting isolated bodies almost perfectly. In a control study designed to verify that the lack of congruency effect could not be attributed to our child-friendly method, adults (n = 12) performed this same task with face/body expressions previously shown to elicit a congruency effect—sad/fear. They made more errors on incongruent trials, $p < .01$. Our data suggest that children's early sensitivity to emotional valence precludes congruency effects for happy/sad expressions, which we are testing in a follow-up study with two to three-year-old children—the youngest children that can reliably sort these facial expressions. Collectively, these results provide novel insights about how and when context influences children's sensitivity to facial expressions.

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33.403 Event Related Potentials Associated With The Modulation Of Spatial Attention By Emotional Faces.

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Being able to attend to the location others are gazing at is crucial to understand people's intentions. This orientation of attention by gaze has been studied using target detection tasks in which a central face cue gazing to the side precedes the appearance of a lateral target. Participants are faster to respond to the gazed-at location (congruent trials) than to the non-gazed at location (incongruent trials). Whether this gaze orienting effect (GOE) is modulated by facial expressions is still debated. A GOE enhancement has been reported with fearful compared to neutral faces and attributed to increased arousal or emotional valence.

In the present experiment, we compared the effects of fearful and surprised expressions, previously unstudied, on the GOE at the behavioral and neural level, using the ERP technique. In a classic target detection task, dynamic faces with averted gaze and displaying fear, surprise or no expression, were presented to 20 participants. The GOE was found for all emotions on reaction times. However compared to neutral faces, the GOE was significantly enhanced when the target was preceded by fearful and surprised faces, for which it did not differ. At the ERP level, an enhanced P1 amplitude in response to the target was found for congruent compared to incongruent trials for all emotions.

Thus, greater allocation of attentional resources at the gazed-at location was found for fear and surprise compared with neutral emotions only on reaction times. It remains possible that a differential emotional effect would be seen on ERPs in response to the cue, which we are currently investigating.

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33.404 Neural Coding of Facial Emotions in the Human Brain

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A distributed network of brain regions have previously been implicated in the neural processing of facial emotions (see Fusar-Polli et al., 2009). Such studies primarily used univariate methods of analysis; however, multivariate approaches allow new questions to be asked regarding the neural codes underlying categorization of facial emotions (e.g. Raizada & Kriegeskorte, 2009). Here we employed multivariate pattern analysis to investigate two questions concerning the neural coding of facial expressions: 1) do occipito-temporal brain regions contain emotion specific activity patterns? 2) If so, how do such activity patterns relate to perceptual categorization? We presented participants with each of the six basic facial expressions (plus neutral) in a block design while concurrently recording the fMRI BOLD signal. We trained a linear pattern classifier to discriminate the brain activity patterns generated by each expression. Voxels input to the classifier were selected from occipito-temporal regions that had high sensitivity to visual stimulation in an independent set of data. Significant decoding of facial emotions was found in each participant tested. Moreover, the errors in the neural classification of emotions significantly correlated with the errors made in a completely independent behavioral categorization experiment (that of Smith & Schyns, 2009). Thus information pertinent to perceptual categorization of facial emotions is present throughout occipito-temporal cortex.

33.405 Effects of attentional load and spatial location on amygdala processing of emotional stimuli

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The amygdala is known to play an important role in the processing of emotion-laden visual stimuli (Morris et al., 1996). Recent neuroimaging studies, however, conflict as to whether the amygdala automatically processes emotional stimuli (Vuilleumier et al., 2001) or is subject to capacity limits of attention (Pessoa et al., 2002). If the amygdala is truly automatic then it should be uninfluenced by attentional load. One potential explanation for discrepant findings may be varying spatial location of emotional stimuli across studies, with the amygdala argued to preferentially process stimuli appearing outside the fovea. The present study aimed to directly test the impact of varying levels of attentional load and spatial location on the processing of emotional stimuli in the amygdala.

BOLD signal (3T GR-EPI) in the amygdala was examined in 16 healthy volunteers while they completed a task requiring them to judge the size of gaps recessed into a diamond (Mattingley et al., 2006). Attending to two gaps at a time, subjects indicated which of the two was larger. Attentional load (low vs high) was manipulated by varying the difficulty of the gap judgment task. Faces displaying a neutral or fearful expression were presented at one of three spatial locations: centrally or 8.76° to the left or right of fixation.

A separate behavioral experiment demonstrated the effectiveness of our attentional load manipulation, such that high load resulted in significantly reduced accuracy on a secondary task than did low load, $t(20) = 4.23$, $p < .05$. Preliminary results indicate a significant reduction in amygdala reactivity to fearful faces under conditions of high relative to low attentional load.

Thus, present results confirm earlier findings that the amygdala is sensitive to manipulations of attention. Furthermore, effects of varying spatial location of emotional stimuli on amygdala processing will be discussed.

33.406 Online interaction between conscious and non-conscious perception of emotions in “affective blindsight” depends on low spatial frequencies

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Affective blindsight refers to the uncanny ability of patients with cortical blindness to discriminate reliably the emotional valence of stimuli they cannot consciously perceive. How can conscious and non-conscious emotion perception coexist and interact in these patients? Here we show that non-consciously perceived facial expressions can interfere with the ongoing recognition of consciously perceived expressions, depending on the spatial frequency of the former. When two emotional expressions are simultaneously presented in a split-field design, but one of the two cannot be consciously perceived because it is projected in the blind field, reaction times to recognize the normally visible stimulus are faster if the non-consciously perceived stimulus is emotionally congruent (e.g., two fearful faces). This effect remains when the facial expressions displayed in the blind field are filtered in low spatial frequencies. However, when the unseen faces are in high spatial frequencies the congruence effect disappears and the recognition of the normally visible emotional expressions is no longer influenced by the expressions displayed in the blind field. The findings indicate that non-conscious perception of facial expressions and their integration with normally visible emotional signals is critically dependent on low spatial frequencies, thereby suggesting a pivotal role of subcortical visual structures.

Acknowledgement: NWO

33.407 Redundancy Effects in the Processing of Emotional Faces

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Extensive work in cognitive and affective neuroscience has shown an advantage in the perception of fearful faces than neutral faces. Much of this work has focused on the processing of a single face presented in isolation, a situation that rarely occurs in the real world. In this study we examined the cognitive and brain basis for the perception of multiple emotional faces. Specifically, we compared the perception of a single emotional face with that of multiple emotional faces, all of which depicted the same facial expression. The multiple faces were either duplicate of the same individual or of different individuals. We ask whether the presentation of multiple faces with the same facial expression alters emotional processing, and whether the redundancy effect is mediated by differences in facial identity. Behavioral experiments showed that facial expression discrimination was facilitated by the presence of multiple faces with the same expression, and that the redundancy gain was unaffected by differences in facial identity. However, this facilitation did not carry over to the processing of subsequent emotional faces. fMRI data showed that viewing multiple faces with the same expression increases activity in the fusiform face area (FFA). However, this increase was restricted to identical faces and not found for faces with different identities. We conclude that the representation of the same type of facial expression derived from different tokens shows perceptual summation rather than averaging.

33.408 Orientation Information in Encoding Facial Expressions

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Previous research showed that we use different regions of a face to categorize different facial expressions, e.g. the mouth region for identifying happy faces; eyebrows and eyes for identifying angry faces. These findings imply that the spatial information along or close to the horizontal orientation might be more useful than others for facial expression recognition. In this

study, we examined how the performance for recognizing facial expression depends on the spatial information along different orientations. Fifteen normally sighted young observers recognized four facial expressions – angry, fear, happy and sad – with 140 different images for each expression. An orientation filter (bandwidth = 23°) was applied to restrict information within the face images, with the center of the filter ranged from 0° (horizontal) to 150° in steps of 30°. Accuracy for identifying facial expression filtered with each of these six filters, as well as for the unfiltered condition, was measured for an exposure duration of 53ms. We computed recognition accuracy as d' to separate discriminability from response bias. For all four facial expressions, recognition performance was virtually identical for filter orientations of -30°, 0° (horizontal) and 30°. Beyond $\pm 30^\circ$ filter orientation, performance declined systematically as the filter orientation approached 90° (vertical). Averaged across observers and the filtered conditions, d' corresponding to the best (between $\pm 30^\circ$ orientations) and worst performance (90° orientation) was 2.85 and 0.61, respectively (cf. 3.43 for the unfiltered condition). Normalized to the performance for the unfiltered condition, performance around the horizontal orientation was highest for identifying happy faces, and least for sad. At 90° filter orientation, performance was the highest for identifying fearful faces, and least for happy. We conclude that the spatial information around the horizontal orientation, which captures primary changes of facial features across expressions, is the most important for recognizing facial expressions, at least for people with normal vision.

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33.409 Uncovering the principles that allow a distinction of conversational facial expressions

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Facial expressions convey both emotional and conversational signals. Research focuses mostly on EMOTIONAL expressions and consistently finds that these can be reliably distinguished along at least two dimensions: valence and arousal. CONVERSATIONAL expressions, i.e. those conveying mainly communicative meaning, are thought to be less emotional laden. Interestingly, we found evidence pointing towards the same first two underlying dimensions for CONVERSATIONAL expressions when presented dynamically. The question now arises: “Is the emergence of the valence and arousal dimensions for conversational facial expressions based on the emotional content of these expressions?” To answer this, we used questions addressing the emotional (Fontaine et al, 2007) and the conversational content separately. If the distinction of conversational expressions is based on the small amount of emotional information they might contain, we expect emotional content questions to allow a separation of those expressions. Ten native German participants answered a set of 27 questions for 6 emotional and 6 conversational expressions, both presented statically and dynamically, using a rating scale. A dissimilarity matrix was computed for the expressions. To uncover the meaning of the first two underlying dimensions allowing expression differentiation, multidimensional scaling (MDS) was used. Our results show that static and dynamic emotional expressions can only be distinguished by means of emotional content questions. For these emotional expressions, the valence and arousal dimensions emerged in the MDS. In contrast, conversational expressions can be distinguished using conversational content questions but not using emotional content questions. Unlike emotional expressions, dynamic information improved distinction of conversational expressions substantially. We found evidence for valence and arousal to be the underlying dimensions for conversational expressions. Our results suggest that the distinction of conversational expressions along the first two dimensions is based on conversational rather than emotional content. Moreover, different types of facial expressions benefit to different degrees from dynamic information.

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33.410 **A computational feed-forward model predicts categorization of masked emotional body language for longer, but not for shorter latencies**

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Schindler, van Gool and de Gelder (2008) showed that a computational neural model which exclusively modeled feed-forward processing and was engineered to fulfill the computational requirements of recognition was capable of categorizing a set of 7 different emotional bodily expressions in very much the same way as human observers did. However, since there was no time limit on the presentation time of the bodily expressions in the human categorization task it was likely that feedback processes were triggered. In this study the performance of the neural model is compared with the human performance when feedback processes are blocked by presenting participants with five masked emotional bodily expressions using a parametric backward masking procedure. These emotional expressions were fed into the model as well. Results show that the longer the SOA latency the closer the performance of the human subjects was to the predicted values by this model. On short SOA latencies, however, the human performance deteriorated, but the categorization of the emotional expressions was still above baseline. This shows that the model is very good at predicting the human performance, but that different processes seem to be playing a role when the visibility of the target is low and the subjects are confronted with emotional information. We concluded that either the feed-forward mechanism has not always sufficient time to efficiently categorize the stimulus (it maybe needs 100 or more milliseconds to work properly), or there is another mechanisms aiding the participant to classify the emotions. The latter could be hinting to the subcortico-cortical mechanism increasing the signal-to-noise ratio when feed-forward processes cannot be efficiently used.

Face perception: Experience and learning

Sunday, May 8, 8:15 am - 12:15 pm

Orchid Ballroom, Poster Boards 411 - 427

33.411 **Do face adaptation aftereffects predict face recognition? Evidence from individual differences**

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Face distortion aftereffects are widely studied, yet there is currently no evidence as to whether these are associated with actual face recognition ability. Indeed, previous studies find developmental prosopagnosics typically show normal-sized face aftereffects. Here, we test whether this apparent contradiction could partly be resolved by the recent evidence that face aftereffects arise from multiple levels of the visual system (Susilo et al., 2010, JoV), and thus typically derive only partially from face-level coding. Our technique relies on the logic that (a) human psychophysical evidence (Susilo et al., 2010, Vision Research) shows broadband-opponent coding of facial dimensions such as eye- or mouth-height, and responses of face-selective cells in monkey inferotemporal cortex increase or decrease monotonically as values on facial dimensions get further from the average (Freiwald et al., 2009); (b) broadband-opponent coding predicts an adaptor a fixed distance from average will produce a larger aftereffect in individuals who have steeper neural response functions; and (c) these individuals should also show better discrimination along the dimension, potentially leading to better recognition of faces. We combine this with (d) a method (Susilo et al., 2010, JoV) for isolating the face-level component of a face aftereffect, as distinct from mid-level or shape generic components: this measures the size of the aftereffect to eye-height altered faces and to physically matched T-shapes varying vertical height of the bar. With 70 participants, we found the eye-height aftereffect alone did not correlate with face recognition (Cambridge Face Memory Test), but the face-specific component of the aftereffect (eye-height-minus-Ts) did correlate with CFMT, most strongly with the noise phase, which places the most demand on recognition of faces

across view change, particularly not based on local features. Results imply a relationship between steepness of individuals' neural response functions in face space and their face recognition ability.

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33.412 **Evidence opposing opponent facial coding**

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Exposure to a face can alter the appearance of faces viewed subsequently. For instance, a male face can make subsequent androgynous faces look female. It has been proposed that these aftereffects are driven by a 'face space' opponent neural code (Leopold et al., Nature Neuroscience, 2001). The centre of this 'face space' is thought to reflect a time average of encountered faces. Exposure to a distinctive face is thought to shift the average toward that face, making previously average looking faces take on the appearance of a face that differs from average in the opposite manner to the initial face - hence an androgynous face looking more female after exposure to a male face. Here we present data that, we believe, pose a fundamental challenge to this account. We simultaneously adapt people to male and female faces in different positions, causing androgynous faces to look more female and male respectively. These effects persist when initial and subsequent faces differ in size, which is usually taken as evidence ruling out the contribution of low-level retinotopically organized coding mechanisms. The existence of simultaneous, opposite facial aftereffects is inconsistent with mediation via a single opponent facial code. Our data are consistent with there being multiple, spatially localised, opponent facial codes. However, we cannot see what functional benefit this arrangement would subservise. Instead, we suggest our data, and facial aftereffects in general, are explicable via a combination of low-level spatial aftereffects (that exaggerate differences in position and orientation) and a bias to categorize indistinct inputs as being opposite to immediately preceding distinctive inputs.

33.413 **Adaptation modulates the electrophysiological substrates of perceived facial distortion: Support for opponent coding**

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In two experiments we determined the electrophysiological substrates of figural aftereffects in face adaptation using compressed and expanded faces. In Experiment 1, subjects viewed a series of compressed and expanded faces. Results demonstrated that distortion systematically modulated the peak amplitude of the P250 event-related potential (ERP) component. As the amount of perceived distortion in a face increased, the peak amplitude of the P250 component decreased, regardless of whether the physical distortion was compressive or expansive. This provided an ERP metric of the degree of perceived distortion. In Experiment 2, we examined the effects of adaptation on the P250 amplitude by introducing an adapting stimulus that affected the subject's perception of the distorted test faces as measured through normality judgments. The results demonstrate that perception adaptation to compressed or expanded faces affected not only the behavioral normality judgments but also the electrophysiological correlates of face processing the window of 190-260 ms after stimulus onset.

33.414 **Facial age after-effects show partial identity invariance and transfer from hands to faces.**

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Background: While expression creates short-term dynamic changes in faces, age imparts a long-term dynamic change. In contrast to the work on expression, how facial age is represented in the human visual system has seldom been investigated with adaptation methods. Objective: As a parallel to our prior work on expression aftereffects, we studied the ability of age adaptation to transfer across face identity, face and non-face visual stimuli and sensory modality. Methods: We investigated facial age aftereffects using a perceptual bias paradigm in 48 healthy subjects. In a first experiment we examined whether face age aftereffects could be generated and how these were affected by changes in identity between adapting and test stimuli. In a second experiment, we asked whether hands, body silhouettes or body images at different extremes of age generated facial age aftereffects.

In a final experiment, we asked whether young and old voices could do the same. Results: Age aftereffects were reduced but still significant when the identity of the face was changed between the adapting and test stimuli. Although body silhouettes and grayscale body images failed to generate age aftereffects in faces, we did find modest cross-stimulus transfer of age adaptation from hands to faces. There was no cross-modal transfer of aftereffects from voices to faces. Conclusions: The effects of identity on age aftereffects parallel our findings for the effects of identity on expression aftereffects, suggesting both identity-specific and identity-invariant components of age aftereffects. Transfer between hands and faces may reflect either the contribution of common properties like skin texture that may be potent age cues, or a convergence of representations at a visual semantic level.

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33.415 Adaptation for perception of the human body: investigations of transfer across viewpoint and pose.

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Background: Faces are important stimuli in social interactions, but the perception of bodies may also play an important role in person identification and inference of emotional state. Adaptation has proven a useful means of exploring face representations in the visual system, and can inform us of the nature of body representations. Body aftereffects may be particularly useful for studying invariance in object representations, as they can be subjected to more drastic manipulations of pose. Objective: Our goals were to determine if body aftereffects could be obtained, and if so, to what degree these show viewpoint and pose invariance. Methods: Headless body images were generated from a realistic 3-D mesh model of the human body created from laser range scans of over 2000 people. Statistical machine learning methods were used to factor body shape variations due to identity from those due to pose. By varying the parameters of the model we can generate realistic body shapes in any pose and viewpoint. In experiment 1, we used different viewpoints of an upright body for adapting images and frontal views for test stimuli. In experiment 2, we used the same frontal view of upright bodies as test stimuli, but compared adaptation with the same upright pose to that with adapting body stimuli in different poses. Results: We found aftereffects for upright bodies that remained significant across viewpoint changes. In contrast, there was minimal transfer of adaptation across changes in pose. Conclusion: Body aftereffects show significant transfer across viewpoint, in contrast to the sharp decreases in face adaptation with change in viewpoint that have been previously reported. Lack of transfer across pose indicates a significant limitation to the invariance of body representations, however.

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33.416 Face adaptation: Comparing norm-based and exemplar-based models

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Face-space models (e.g., Valentine, 1991) have successfully accounted for a range of important phenomena in face recognition. Much of the recent literature has focused on differentiating two possible accounts: Norm-based models, where faces can be encoded with respect to the direction and distance with which they deviate from the central tendency, or norm face (e.g., Rhodes & Jeffery, 2006), and exemplar-based models, where faces are encoded with respect to their distance from all or a subset of previously experienced face exemplars (e.g., Lewis, 2004). High-level visual aftereffects, induced by adaptation from brief exposure to a study face, have provided putative evidence for the norm-based encoding of faces (e.g., Leopold et al., 2001; Susilo, McKone, & Edwards, 2010). Exemplar-based models are purportedly falsified because they are generally believed to make predictions that are qualitatively inconsistent with the observed findings, for example by predicting that aftereffects ought to be centred on the adapting stimulus rather than on the norm. Despite the apparent consensus in the literature regarding norm-based and exemplar-based accounts of these findings, there have been few attempts to explicitly simulate norm-based and exemplar-based models to assess their qualitative and quantitative predictions. Here we explored the theoretical accounts of face adaptation, instantiating two versions of the norm-based model, a traditional norm-based model and a two-pool norm-based model, along with an exemplar-based

model. In contrast to the consistent claims in the literature, we found that both the exemplar-based model and the two-pool model, but not the traditional norm-based model, made predictions that were qualitatively and quantitatively consistent with the findings in the literature across a wide range of model parameters.

Acknowledgement: ESRC

33.417 Selectivity of facial aftereffects for changes in facial expression

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Adaptation to configural distortions in faces has been found to show selectivity for some changes in facial identity (e.g. for different individual faces, genders, or ethnicities), while strongly transferring across some stimulus dimensions that preserve perceived identity (e.g. differences in image size or mean color). We asked how the adaptation adjusted to variations in facial expression, to assess whether a change in expression was equivalent to adaptation to the "same" or a "different" face. Stimuli were frontal view images of Dutch female or male faces with happy or fearful posed expressions from the Radboud Face Database. The images were distorted by a local horizontal expansion or contraction of the face relative to a midpoint on the nose. Observers adapted for 2 min to a single distorted face or to an alternation between two faces with opposite distortion (from the same individual with different expression or different genders with the same expression). Test faces were the same as the adapt face(s) or a face with different expression or gender, and were shown 1.5 times smaller than the adapt images to reduce low-level aftereffects. The tests alternated with 4 sec readaptation intervals, with the distortion level varied in staircases to estimate the level that appeared undistorted. In adaptation to either the single or opposing face pairs, aftereffects showed modest selectivity (equivalent to ~ 80% transfer) for the change in expression. However, the degree of transfer was roughly comparable to changes in the gender of the faces. The results thus suggest that natural forms of intra- and inter-individual variations in the face have roughly similar effects at the levels affected by the adaptation, and specifically that at least part of the adaptation precedes sites at which different expressions of the same face are represented as an equivalent identity.

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33.418 Contrast dependence of figural aftereffects for faces

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Neural responses to shapes and faces in higher visual areas show relatively little dependence on stimulus contrast. We examined whether the effects of physical contrast on adaptation to faces was consistent with sensitivity changes at these more contrast invariant sites. Stimuli were grayscale images of frontal-view faces cropped to remove the external features of the head. The faces were distorted by locally expanding or contracting the image relative to a midpoint on the nose. Observers adapted for 2 min to a distorted face and then judged the distortions of 1 sec test faces interleaved with 4 sec readaptation intervals, with the test distortion varied in a staircase to determine the image that appeared undistorted. Test faces were 1.5 times smaller than the adapt faces to reduce effects of low-level retinotopic adaptation. Luminance levels in the test and adapt images were scaled to span a wide range of contrasts, with scaling relative to the mean luminance level in the cropped face. Additional image sets flattened the contrast variations within the face to control for the large luminance differences within the eye region. Aftereffects to the distorted faces showed relatively weak but significant effects of stimulus contrast. Pronounced aftereffects were induced in a full contrast face even by adaptation to faces with contrasts 16x lower that were near the threshold for recognition. The contrast response for adaptation to the face distortions was thus similar to other high-level figural aftereffects in implicating a central site of the sensitivity change. The face aftereffects are also selective for the polarity of luminance contrast, and in further experiments we examine the effects of these polarity differences both in the full face or restricted (eye) regions.

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33.419 **Perceptual learning induces fast processing and efficient representation of face**

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Perceptual learning can significantly improve the capability of the adult visual system for object recognition and discrimination, yet little is known about how learning affects object processing and representation in the brain. Here, we combined EEG and psychophysics to study the neural mechanism of perceptual learning of face view discrimination. We trained subjects to discriminate face in-depth orientations at a face view (i.e. 30°) over eight daily sessions (8000 trials in total), which resulted in a significant improvement in sensitivity to the face view orientation. Before and after the 8-day training, we measured subjects' face orientation discrimination thresholds at the face views of -90, -60, -30, 0, 30, 60, and 90° (minus means left tilt), and EEG signals induced by the trained and untrained face views were recorded. We found that this improved sensitivity was highly specific to the trained view. EEG data showed that, after training, the peak latency of N170 at the left occipito-temporal area evoked by the trained view was significantly shortened (about 8ms) and the 50-90 Hz gamma power at the left prefrontal area induced by the trained view was significantly reduced between 100 and 200 ms after stimulus onset. Parallel to the psychophysical finding, the N170 latency shortening and the gamma power reduction were also specific to the trained face view. Previous researches have demonstrated the close relationship between N170 and face configural perception and the existence of face selective neurons/areas in the prefrontal area. Some theoretical and empirical studies suggest that gamma power reduction means a more efficient cortical representation of a stimulus. We conclude that face view discrimination training could lead to faster processing and a more efficient representation of face. These results provide important constraints on the neural model of high-level visual perceptual learning.

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33.420 **Perceptual Learning of Inverted Faces across Different Spatial Frequency Bands**

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Practicing a perceptual task can improve the ability to detect, discriminate, and identify stimuli, a phenomenon known as perceptual learning (1). Improvements have been found for simple and complex visual stimuli, including upright faces (2,3). However, little is known about the effects of practice on recognition of inverted faces (4,5). Here we hypothesized that adults might be better at learning to recognize inverted faces if trained with low spatial frequency images (<5 cpi; LSF) than full spectrum (FULL) or high spatial frequency images (>24 cpi; HSF) since newborns learn to recognize upright faces despite poor visual acuity (6). We trained 3 groups of 16 adults in a 10-AFC task with LSF, HSF or FULL inverted faces presented with different viewpoints. Participants were exposed either to the same or a different set of faces on Day 2. Although reaction times became significantly faster for all groups during training, accuracy improved only in the FULL (14%) and HSF (7%) groups. In contrast, the LSF group's overall improvement was only 1% (Fig1). Improvements from before to after training were assessed by comparisons to an untrained control group on 4 tasks. The FULL group showed more improvement in both accuracy and reactions time than controls on the delayed matching task of full spectrum inverted faces, thereby demonstrating generalization of training to novel faces. They were also faster on the same task with upright faces. The HSF group showed increased and decreased holistic processing of full spectrum inverted and upright faces, respectively, as indexed by reaction times on the composite face effect. Despite no improvement in accuracy during training, the LSF group improved more than controls on reaction times to match simultaneously presented full-spectrum inverted faces. These results suggest that perceptual learning of inverted faces and its generalization depend strongly on their spatial frequency content.

33.421 **Implicit face prototype learning from geometric information**

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There is evidence that humans implicitly learn an average or prototype of previously studied faces, as the unseen face prototype is falsely recognized as having been learned (Solso & McCarthy, 1981, Br. J. Psychology).

Here we investigated the extent and nature of face prototype formation in a multidimensional face space with a face learning and old/new discrimination experiment. Observers first studied eight synthetic faces defined by geometric information in a 37-dimensional face space (Wilson, Loffler, & Wilkinson, 2002, Vision Research). These faces were equidistant from the unseen prototype and comprised face, anti-face pairs along four axes with the unseen prototype as origin. After studying the faces for 30 s each, memory was tested using a series of test faces, each flashed for 240 ms. Test faces included previously studied faces, the unseen prototype, and eight novel distractor faces defined by four new axes in face space with a face and anti-face on each. Results showed that the unseen prototype was falsely identified as learned at a rate of 86%, whereas studied faces were identified correctly 66% of the time and the distractors 32%. This lasts at least one week. Additional studies demonstrated flexibility of prototype learning: the learned prototype could be either the face-space population mean or a highly distinctive non-mean face. Contrary to previous results (Cabeza et al., 1999, Memory & Cognition), this prototype effect for geometric face information also generalized across viewpoints, as the unseen prototype of faces rotated 20° was also falsely recognized after studying frontal views of the same faces (and vice versa). Further experiments suggest that head shape and internal features separately contribute to prototype formation. Thus, implicit face prototype extraction in a multidimensional space may be a very general aspect of geometric face learning.

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33.422 **Visual familiarity influences representations of faces**

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We are extremely good at recognizing the faces of people we know even from highly impoverished stimuli, such as pictures that are highly distorted or blurred. However, when we are unfamiliar with someone, our recognition of their face is much slower and more prone to error. Research has shown that when we are only briefly exposed to unfamiliar faces, we often fail to recognize them and that we can even fail to accurately match two pictures of the same person that are simultaneously presented (e.g. Bruce et al., 1999; Burton et al., 1999). Our aim is to study the changes in behavioral performance as we become familiar with faces. We trained participants to recognize the faces of eight unfamiliar individuals. Participants were trained on three separate days. In one of the tasks, participants had to match two faces across different views and lighting conditions. In another task, participants selected one of the studied faces among two distractors. Participants' performance improved gradually across the three training sessions. At the end of the training, participants performed 20% to 30% better on both tasks compared to their performance in the initial session. Crucially, when they were tested with eight new faces, participants' performance was significantly worse than with the learned faces, demonstrating that most of the training effect is specific to the faces that were learned. We suggest that this change in performance reflects a change in the representations of the faces that were learned. We believe that this change depends only minimally on semantic information but instead reflects modifications of the visual representations of the faces that were learned. In follow-up fMRI studies, we will examine neural changes that accompany this face learning effect.

33.423 **The time course of individual face processing**

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Whether the entry point of face recognition is at the individual level (e.g. Brad Pitt) or at the superordinate level (e.g. human) when processing familiar faces is unclear. We measured reaction times (RT) in a speeded go no-go task in two different conditions: at a superordinate level (unknown human faces among animals faces) and at an individual level (famous faces among unknown faces). In experiment 1 participants (n=31) categorized stimuli by releasing a response button as quickly as possible when they saw a target (270 targets, 270 distractors for each condition). In experiment 2, subjects (n=7) underwent 4 additional sessions of Experiment 1 with learning sessions of all targets in between. Experiment 1 demonstrates that individual faces require 200ms longer to be categorized than human faces, whether computing minimum RT (359ms vs 559ms) or median RT (439ms vs 635ms). An unexpected result was that 3 subjects were much faster than

other participants in the individual condition (median RT 393ms vs 479ms). Those fast subjects showed a 100 ms difference between superordinate and individual conditions. Experiment 2 revealed that subjects improved their RT but could not go below a 100ms RT difference between the two conditions. Interestingly, the “fast” subjects identified in Experiment 1 could not improve their RT. Results show, in contrast to numerous studies, that additional time is required to categorize a face from a superordinate to an individual level. We identified two additional stages after the superordinate level, one short with an incompressible cost of ~100ms, probably related to visual familiarity processes, the other longer with a cost of ~200ms probably also including semantic activation. Therefore individual faces are processed hierarchically following the classic visual ventral stream hierarchy, at least when individual faces can't be preactivated (“bottom-up recognition”) like in those experiments.

33.424 Beyond the retina: Evidence for a face inversion effect in the environmental reference frame

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Over 50 years of research has demonstrated that orientation dramatically affects the visual processing of faces; across a wide variety of perception and memory tasks, observers show markedly worse performance when faces are presented upside-down compared to upright. However, the meaning of orientation (i.e. what counts as upright) must be established in relation to a particular reference frame. In most experiments, several reference frames are conflated: upright faces are upright with respect to the participant's retinal frame, but also with respect to environmental frames such as the layout of the experiment room and the directional pull of gravity. Here we ask: in relation to which reference frame(s) does the face inversion effect occur? We developed a novel, simple method for investigating potentially independent effects of retinal and environmental reference frames in face perception. Participants performed one of two face-processing tasks as they lay horizontally, thereby disassociating the retinal and environmental orientation of the stimuli. In Study 1, participants judged the emotional expression of Mooney faces; in Study 2, participants performed an old/new recognition task on novel face images. In both studies, we found a large effect of retinal orientation on performance and a reliable (though smaller) effect of environmental orientation. Specifically, participants in Study 1 were faster and more accurate at judging emotional expressions of environmentally upright versus environmentally upside-down faces, even though faces in both conditions were rotated by 90 degrees in the retinal frame. Similarly, recognition performance in Study 2 was better for environmentally upright versus environmentally upside-down faces. In two control studies, we ruled out alternative explanations of our findings based on the design of our stimuli and the experimental apparatus. We conclude that there exists a reliable effect of environmental orientation on face processing that is revealed when retinal orientation is held constant.

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33.425 Identifying faces across large changes in illumination: Human versus machine performance

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In natural environments, face identification must operate robustly over changes in illumination. We examined identification under uncontrolled illumination conditions using a constant set of identities that varied in photometric difficulty across multiple images. Photometric difficulty was estimated using a face recognition algorithm created by fusing three top-performing algorithms from a recent international competition. The algorithm computed similarity scores for same-identity and different-identity pairs from multiple images taken under a variety of uncontrolled illumination conditions (both indoors and outdoors). For each identity pair, algorithm-generated similarity scores were ranked and divided into three machine performance groups: good, moderate, and poor. Algorithm performance across these constant identity pairings varied widely. In three experiments, humans matched identity in image pairs from the good, moderate, and poor groups. In Experiment 1, participants matched 240 pairs of faces (120 same-identity) from all three conditions, rating the likelihood that the images were of the same person (1: sure same - 5: sure different). Humans performed best for the good pairs, and equivalently for the moderate and poor performance pairs. Algorithm accuracy surpassed humans, although

the algorithm advantage decreased as the challenge level increased (from good to poor). Experiments 2 and 3 replicated these results using a larger number of face pairs from only the moderate and poor performance conditions. In a fourth experiment, humans matched identity on image pairs that yielded systematically incorrect performance for the algorithm (i.e., an infinitely negative ROC curve). Specifically, the same-identity pairs had algorithm-generated similarity scores that always were lower than the similarity scores for different-identity pairs, (i.e., same- and different-identity distributions reversed). Human performance was well above chance ($d' = 1.5$). In summary, as the level of photometric challenge increased, the performance advantage for algorithms over humans diminished, ultimately reversing to a human advantage for the most difficult cases.

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33.426 Using avatars to explore height/pitch effects when learning new faces

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In a previous series of desktop experiments we found no evidence that individuals' height influenced their representation of others' faces or their ability to process faces viewed from above or below (VSS 2009). However, in those experiments face orientation and body height were ambiguous as isolated faces were shown on a computer screen to an observer sitting on a chair. To address those concerns and to specifically examine the influence of learned viewpoint, we created a virtual museum containing 20 full-bodied avatars (statues) that were either sitting or standing. Using a head-mounted display, observers walked through this virtual space three times, approached each statue and viewed them from any horizontal (yaw) angle without time restrictions. We equated eye-level - and thus simulated height -- for all participants and restricted their vertical movement to ensure that the faces of sitting avatars were always viewed from above and standing avatars from below. After familiarization, recognition was tested using a standard old-new paradigm in which 2D images of the learnt faces were shown from various viewpoints. Results showed a clear influence of learned viewpoint. Faces that had been learned from above (below) were recognized more quickly and accurately in that orientation than from the opposite orientation. Thus, recognition of specific, newly learned faces appears to be view-dependent in terms of pitch angle. Our failure to find a height effect in our previous study suggests that the variety of views of human faces experienced during a lifetime and possibly the preponderance of conversational situations between humans at close range typically counteracts any influence that body size might have on a person's viewing experience of others' faces.

33.427 Avatars versus point-light faces: Movement matching is better without a face.

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Facial movement may provide cues to identity, by supporting extraction of shape information from the face, or via idiosyncratic individual motion patterns. Although previous studies have examined whether recognition of familiar or unfamiliar faces can benefit from motion, it is rare that the two are compared directly. Furthermore, they have generally used different methods and stimuli, leading to difficulty in determining whether movement benefits familiar and unfamiliar faces to the same extent. We present two studies assessing the movement advantage in faces, by using facial point-light-displays (PLDs) or shape-averaged avatars. Experiment 1 tested the matching of famous and unfamiliar faces in a same/different task, using the same stimulus type within each pair. Matching performance was better for PLDs than for avatars, and for familiar compared to unfamiliar faces. There was a significant advantage for matching moving images compared to static images for both familiar and unfamiliar faces, although this was larger for unfamiliar faces. Experiment 2 also used a same/different task, but participants attempted to match non-degraded images of famous and unfamiliar faces to PLDs or avatars. Overall performance in Experiment 2 was lower than Experiment 1. Once again, matching performance was better for PLDs compared to avatars, and familiar compared to

unfamiliar faces. A movement advantage was present for unfamiliar faces only. The performance differences between PLDs and avatars, and between Experiments 1 and 2, indicate that the benefit derived from viewing a face in motion depends on the type of information contained in stimuli and the task. Although participants are capable of generalizing between movement sequences in a matching task, it is more difficult when the format of the sequences is varied. Overall, these results suggest that movement can provide a useful cue to identity, particularly for unfamiliar faces.

Perception and action: Reaching and grasping

Sunday, May 8, 8:15 am - 12:15 pm

Orchid Ballroom, Poster Boards 428 - 444

33.428 A perception-action dissociation revealed through the interaction with blurred stimuli.

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In the perception-action model of vision (Milner & Goodale, 1995), information is passed from lower visual (e.g. V1) areas into two processing streams: a dorsal stream mediating visually guided movement, and a ventral stream mediating object identification and awareness. Information processed prior to the bifurcation should therefore be available to both streams. This experiment examined how the quality of a luminance edge (processed at V1) would influence perception and action. A grasping task, and a perceptual size-matching task were performed under full-vision (FV) and 2-s delayed vision (DV). Stimuli varied in size (3), and edge-blur (4). Edges were blurred using a 2D Gaussian-filter. Maximum-grip-aperture (MGA) was the size-estimate for grasping, while perceptual-estimates (PE) required participants to estimate the size of stimuli by adjusting the size of a comparison stimulus. It was predicted that, the visual streams would use the same edge information, and thus motor and perceptual judgements would behave in a similar manner under both FV and DV. PE and MGA increased with increases of stimulus size, and decreased with increasing degree of blur. An analysis of the rate of scaling to size across conditions revealed that PES scaled at a higher rate to changes in size than MGA. Scaling based upon level of blur exhibited a two-way interaction between task and visual condition. MGA blur-scaling was not altered by DV, whereas PES blur-scaling became significantly more shallow. This violated the expectation that under DV, an increase in similarity between motor and perceptual responses would be found. Since PES became less influenced by edge blur following a delay while MGA scaling remained unchanged, there is evidence that the perception/action systems hold different representations of certain stimulus properties. Thus, the two-visual streams appear to generate their own representations of edge location even though similar edge information is available to both.

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33.429 Passive tracking versus active control in motor learning

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Learning a motor skill requires production of qualitatively appropriate movement that can be fine-tuned (Newell, 1991) but children with disabilities, such as developmental coordination disorder (DCD), often cannot achieve this qualitative success independently (Clark et al., 2005; Smits-Engelsman et al., 2001). Passive modeling has been used to help learners accomplish the necessary approximation, but this approach frequently fails to work well (Kwakkel et al., 2008). Action theory suggests learners need to actively generate movements to be successful (e.g. Bingham, 1988) but it can be difficult to improve motor performance when reliable approximations of a target action are not available. Snapp-Childs et al. (2010) developed a method that enables children with DCD to overcome this 'catch-22' and improve manual performance to match typically developing children. In this study, we conducted a strong test of the role of active versus passive motor performance in the improvements found in Snapp-Childs et al. (2010). Fourteen adults completed 12 baseline trials where the task was to use a stylus (Phantom Omi) to push a bead quickly along a wire path in a 3D virtual environment; in these trials, magnetic attraction to the wire path systematically decreased thus increasing task difficulty. Half of the participants then completed 3 sessions of 36 active trials with varying levels of

attraction, while the other half were given comparable passive experience manually tracking the trajectories. After training, both groups repeated the baseline and 4 novel trials (with longer, more complex, paths). Before training, there were no differences between groups in trial duration. The active group, however, performed significantly better than the passive tracking group after training (12.1s vs. 15.4s, $p < 0.05$). This effect was strongest in the novel trials (26.7s vs. 40.8s, $p < 0.05$) that required generalization. Active control during training aids generalized motor learning.

33.430 Visuomotor resolution for size is independent of conscious perception

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Human resolution power in the various senses is experimentally determined by a range of known psychophysical methods. A trivial yet critically important feature of classical psychophysics is that its methods are based on conscious perception. In contrast, grasping of the same stimuli might be less conscious. Recent findings from our laboratory showed that Weber's law, a pillar of classical psychophysics, does not necessarily hold when people grasp rather than perceptually evaluate the size of objects presented for view. Moreover, the trajectories of the fingers during grasping can be dissociated from people's conscious perception of size. In the current study, we integrated these two lines of evidence in order to compare grasping and perceptual sensitivity to differences in size that were set below the Just Noticeable Difference (JND). In Experiment 1, participants were asked to make size comparisons for pairs of objects and then to grasp the objects. In a second experiment, a similar paradigm was used but now subjects made perceptual estimations of size instead of grasping. The results showed that perceptual estimations were not sensitive to differences in size smaller than the JND. This pattern of results was found for both correct and erroneous size-comparisons trials. In contrast, grasping trajectories showed sensitivity to object size differences regardless of the JND. This pattern was observed even in trials in which perceptual size comparison were erroneous. Participants were not aware, therefore, whether their size discrimination via grasp was or was not veridical. These findings show that human resolution power is not fully captured by the classic perceptual JND. Grasping can exhibit greater resolution power than that measured via conscious visual perception.

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33.431 A Modern Version of a Classic: Combining the Cross Copy Task with a Computerized Tablet Reveals Subtle Motoric Deficits in Hemispatial Neglect
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Figure-copying tasks capture fundamental aspects of visuomotor cognition, which include motor planning/execution, spatial attention, and visuomotor feedback processing. Correspondingly, these tasks are widely used for neuropsychological assessment of visuomotor and visuospatial abilities such as identifying deficits in patients with hemispatial neglect. However, copying assessments are typically scored in a coarse manner, lacking real-time detail. To improve these methods, we had participants draw a symmetrical 12-segment Greek cross on a piece of paper (Reitan, 1963) placed on a computerized tablet, allowing us to measure the precise length, velocity, and initiation time of each line segment. Participants drew the cross in both clockwise and counter-clockwise directions as well as with and without ink (visible and invisible conditions). This allowed the separate analysis of leftward or rightward motion in various positions as well as how participants use visual feedback. To validate this task, we compared performance of patients suffering from hemispatial neglect with a group of healthy age-matched controls. Although many neglect patients scored in the normal range using traditional scoring methods based on the appearance of the overall figure, details of the movements were significantly different from healthy controls. In particular, left-hemifield neglect patients had slower velocities when moving rightward on the left side of the figure compared to movements on the right. Additionally, several neglect patients demonstrated generally slowed leftward initiation times. These abnormalities were more evident during visible than invisible trials, suggesting that

perceptual aspects of the emerging figure disrupt patients' ability to guide motor performance. These results suggest that combining a computerized tablet with a simple copying task can provide new and clinically useful information, particularly with regard to motoric aspects of visual neglect. Such simple naturalistic tasks, in turn could lead to the development of shorter, more sensitive, and more clinically relevant assessments of visuomotor disorders.

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33.432 **The role of right temporal lobe structures in off-line action: evidence from lesion-behaviour mapping in stroke patients**

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Recent evidence suggests the possibility that not all action modes depend on dorsal visual stream processing but that off-line actions, such as anti-pointing, require additional and even distinct neural networks when compared to target-directed on-line actions. Here we explored this potential dissociation in a group of 11 patients with left visual neglect, a syndrome characterized by a loss of awareness of the contralesional side of space. Ten healthy participants and 10 right-hemisphere damaged patients without neglect served as controls. Participants had to either point directly towards targets presented on their left or right (i.e. pro-pointing) or to their mirror position in the opposite hemisphere (i.e. anti-pointing). Compared to both control groups, neglect patients showed reduced accuracy when anti-pointing, but not pro-pointing, to both sides of space. Lesion-behaviour mapping revealed that the areas critically associated with these deficits were located in the middle, superior temporal and parahippocampal gyri. We argue that neglect patients present specific deficits only when the visuomotor task taps into more perceptual representations thought to rely on ventral visual stream processing and that our results indicate that temporal brain regions are implicated in these off-line actions. We will also demonstrate that the relatively spared on-line actions can be exploited successfully for rehabilitation.

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33.433 **The role of proprioception in the planning and control of action following sensory deprivation**

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Both vision and proprioception operate in the planning and control of action (Touzalin-Chretien et al., 2010). However, vision has been reported as the dominant sensory modality (Heath, 2005). As such, vision is preferred over proprioception when vision is available (Touzalin-Chretien et al., 2010). Of interest, then, is the role of proprioception in motor tasks when vision is absent, and what changes in the brain may result from visual deprivation with respect to proprioception. The current study employed a 2-hour visual deprivation to differentiate proprioception from vision by removing visual input. During the visual deprivation, subjects participated in tactile discrimination tasks to promote proprioceptive plasticity. Prior to and following deprivation participants were asked to perform a grasping task under either visual (Vision) or proprioceptive (No-Vision) control (40 trials each: 160 total). For every trial, an experimenter passively moved the subject's right hand to the target and back to a set origin. In No-Vision trials, participants grasped either a small (5cm diameter) or large (7cm diameter) circular target at two different locations (20 or 35 cm) in response to an auditory tone. In Vision trials, vision was made available 2s prior to the auditory tone until movement end. Participants were instructed to grasp the target as quickly and accurately as possible. PLATO goggles (Translucent Technologies, Inc.) were used to remove visual input during the deprivation and No Vision condition. Kinematic measurements (e.g. grip aperture, reaction time, movement time) were obtained using an Optotrak 3020 (Northern Digital, Inc.). Results indicated augmented use of proprioception for motor planning, but less so for motor control of reaching and grasping strategies following acute visual deprivation. Our results are consistent with findings that sensory deprivation is associated with plasticity and behavioral changes (Merabet & Pascual-Leone, 2010).

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33.434 **Dynamic early adherence and late violation of Weber's law in goal-directed grasping.**

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An exemplar metric of goal-directed grasping (i.e., peak grip aperture) has been shown to be refractory to a psychophysical principle governing visuoperceptual estimations of object size (i.e., Weber's law: Ganel et al. 2008: *Curr Biol*). This dissociation suggests that vision for action and vision for perception are mediated by absolute and relative visual information, respectively. The present investigation examined whether aperture shaping elicits a unitary or time-dependent violation of Weber's law. To address this issue we asked one group of participants (i.e., perceptual task: N = 11) to provide a pantomime size estimation of differently sized objects (20, 30, 40, 50 and 60 mm of width) and had a separate group of participants (i.e., motor task: N = 16) complete goal-directed grasps of the same objects. For the perceptual task, just noticeable difference (JND) scores were computed when participants indicated that their hand opening matched the size of the target object. Importantly, motor task JNDs were computed at peak grip aperture as well as at normalized deciles of the response (i.e., 10% through 90% of grasping time). As expected, JNDs for the perceptual tasks increased with increasing target size (i.e., Weber's law). For the motor task, JNDs during the early and middle stages of the trajectory scaled to object size whereas values late in the trajectory (> 50% of grasping time and including the time of peak grip aperture) did not. In other words, results for the motor task show an early, but not late, adherence to Weber's law. These results indicate that actions are not specified by a unitary and absolute visual code; rather, the time-dependent scaling of JNDs indicates a dynamic interplay between early movement programming via relative visual information and later movement control via absolute visual information.

33.435 **Walking, climbing, grasping: Separate visual processing streams for different classes of actions**

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The action observation pathway comprises areas in posterior superior temporal cortex and in parietal and premotor cortex. Recently, we could show that the parietal cortex is organized based on the action that is performed and the premotor cortex based on the effector employed. However, all stimuli used in the study showed fine manipulative actions (Jastorff et al. 2010). In this new study, we investigate the organization of the action observation pathway with respect to a broader class of actions. In a human fMRI experiment, we presented videos of three classes of actions: locomotion (walking), locomotion with the aid of hands (climbing) and fine manipulative hand actions (grasping). Static frames of the videos and random dot texture patterns animated with the optic flow present in the original videos served as control conditions. We obtained a significant interaction between grasping and walking and between grasping and climbing and thus enhanced activation for grasping compared to other action classes in pAIP and ventral premotor cortex. Stronger responses for climbing compared to walking and climbing compared to grasping were obtained in the SPL dorsal to the IPS and posterior to the post central sulcus, extending up to SPOC (Cavina-Pratesi et al. 2010). This activation also extended towards the medial side of the brain. The results for the interaction between walking and grasping were similar to the ones between climbing and grasping, however the activation sites were smaller. The interaction between walking and climbing was not significant. Our results indicate separate processing streams for fine manipulative actions on the one hand and locomotion on the other hand. Climbing actions, which include grasping with the hand as one component lead to similar activations as normal locomotion, yet the activation in the SPL is more extended.

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33.436 **Gaze strategies during visually-guided and memory-guided grasping**

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Vision plays a crucial role in guiding motor actions. Previous work in our laboratory has shown that initial gaze position is tightly linked to eventual grasp position, specifically of index finger placement during a precision grasp on symmetrical objects (Desanghere & Marotta, 2008). In contrast,

perceptual tasks reveal gazes falling closer to the centre of mass (COM) when subjects look at computer-generated objects. But many grasping actions can be performed using our memory of the object's shape and location to guide our actions. For example, imagine glancing at the coffee mug on your desk but focusing your attention back on your computer screen as you reach out to grab your mug. Where do we look at objects to collect visual information about them when the objects are a target for future memory-guided grasps? This study was aimed at addressing this issue. Subjects reached out and grasped centrally placed symmetrical blocks under either closed-loop (visually-guided) or open-loop (memory-guided) conditions. In the memory-guided condition, subjects were shown the block for 1 s, controlled by shutter glass, and then prompted to make an open-loop grasp either immediately after the shutter closed or after a 2 s delay. Results show peak hand velocity was fastest during closed-loop reaches and slowest during open-loop reaches. Open-loop grasps were more rightward of the blocks' COM relative to closed-looped grasps. Initial gaze fixations during closed-looped grasps were directed to the top of the blocks corresponding to the index finger's grasp point, suggesting gaze targets future grasp points during the planning of the grasp. In the memory-guided condition, subjects spent more time looking closer at the centre of the block, suggesting subjects analyse the block's overall shape to build a holistic perceptual representation for open-looped actions.

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33.437 Perception and the Fitts's Law Violation: Why is the last one the fastest one?

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Fitts's Law (FL) quantifies the tradeoff between speed and accuracy for manual movements, and it predicts that movement time (MT) increases logarithmically as the movement amplitude (i.e., distance) increases when target width is held constant. Replicated hundreds of times over 50 years, FL has proven to be incredibly robust; however, a violation of this law has recently been discovered. When targets of a constant width are placed in a structured perceptual array (e.g., visible placeholders denoting potential target locations), MTs to targets in the last position of the array are much shorter than predicted by FL (often shorter than MTs to targets at the second-to-last position). This violation holds for manual, saccadic, and even imagined, movements. Although it is known that the violation occurs in the movement planning stage, the underlying driving mechanism remains unknown. In the current study, we conducted three experiments to determine if the violation has a perceptual cause. In the first experiment, by measuring MTs to locations demarcated by extremely diminished placeholders (3 pixels long), we show that the violation does not occur due to perceptual interference. Experiment 2, which measured reaction times using a target detection task, showed that subjects are no faster in detecting targets appearing in the last location than they are detecting targets appearing at the other positions. Experiment 3, which measured accuracy using a brief presentation target identification task, showed that targets presented at the last position in the array are identified equally accurately in both placeholder present and absent conditions. Overall, these findings indicate that the changes in effectiveness of visual processing at the last position in the perceptual array do not drive the FL violation. Thus, while the locus of the FL violation appears to be in the movement planning stage, it is not due to perceptual mechanisms.

33.438 Spatial bias, spatial uncertainty and illusion effects in antigrasping

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In a virtual reality (VR) setup we let participants grasp bar stimuli with a precision grip. In an orthograsp condition physical and VR stimuli were at corresponding locations. In an antigrasp condition physical stimuli were located opposite to stimuli displayed in VR, similar to the well established anti-saccade paradigm.

In three experiments we varied the amount of spatial uncertainty of stimulus position by changing stimulus size and permitting auditory location cues. In two of the experiments we used Mueller-Lyer type illusory displays. Here we also measured the perceptual effect of the illusion with a size estimation task.

We found that participants exhibited a movement bias towards the location of the visually displayed stimulus in antigrasping. Antigrasping in interaction with spatial uncertainty also had a diminishing effect on maximum grip aperture (MGA) scaling. Other kinematic parameters - reaction time, movement time, size and timing of MGA - showed no significant difference between ortho- and antigrasping. Presenting the Mueller-Lyer stimuli had a highly significant effect on perceptual size estimates and on MGA size in anti- and orthograsping.

We conclude that spatial movement biases are present in antigrasping that are analogous to those found in antisaccades. Antigrasping seems to impose higher demands on the visuo-motor transformations from perception to action which become evident when the task gets more difficult.

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33.439 Error statistics reflect movement coding and prior movement history

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Two movement codes appear to underlie reach planning: an endpoint code based on final desired hand position, and a vector code defining the desired movement distance and direction. Previous work on movement coding relies on modified sensory information concerning each code or different movements for studying each code. Instead, we examine predictions for these two coding systems while keeping the task, biomechanics, and sensory inputs constant. We do this by controlling recent movement history, which allows us to examine predictions for the error statistics of the two systems. A vector code describes movements in incommensurate (distance-angle) units. One therefore expects anisotropic reach errors with error covariance aligned with the reach direction, as is often found experimentally. Endpoint-coded reaches are given in spatial position (i.e., x-y) units, which one expects to have roughly equally scaled internal representations and corresponding isotropic xy-errors. Subjects performed 12 repetitions of 36 reaches (six targets, and six start positions equally spaced around each corresponding target), in two 'groupings'. In 'target grouping', all reach repetitions to one target are performed (6 start positions randomly chosen), and then all reaches to another target, until all targets have been completed. In 'vector grouping', all repetitions of one vector (i.e., same relative start position) are performed (6 targets randomly chosen), and then another vector, until all six vectors are completed. Although the same 36 reaches are performed in both groupings, the latter provides better practice for a vector coding system, while the former provides practice for an endpoint coding system. Not only do 'vector-grouped' and 'target-grouped' reaches display the predicted error anisotropy and isotropy (respectively), but target-grouped errors are isotropic even if covariance is computed after sorting by reaches with a common movement vector - suggesting that the more-practiced endpoint code dominates target-grouped reach plans, resulting in isotropic error covariance.

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33.440 Cognitive feedback may cause "Tool Effects": An attempted replication of Witt (in press)

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We sought to follow up reports that perceived distance is reduced when wielding a tool that extends reach. Several studies have contrasted distance estimation between groups that reached to a target using only their hand and reached using a tool. The present study aimed to replicate one such finding, which used an "implicit" measure of distance (triangle aspect ratio). Because others have shown that people overestimate how far they can reach (and underestimate distances along a table), we sought to test whether reaching with one's hand provided distance feedback for future trials that produced the reported differences between conditions. Methods. Our experimental design painstakingly replicated the main conditions of Witt (in press), Experiment 1, but added a third condition in which no reaching was performed. A questionnaire after the main experiment assessed participant strategies and observations. Estimates of reach along the table and

measures of actual reach were collected after the questionnaire. Results. We found no effect of the tool on estimates of perceived aspect ratio. However, we replicated the more general findings that (1) aspect ratios were underestimated and (2) reachable distance was overestimated. The questionnaire data showed that about two-thirds of participants in the hand condition noticed that they were underestimating distances along the table, and about half of these explicitly mentioned getting feedback from reaching. On average, people underestimated the aspect ratios by about 10%, while overestimating how far along the table they could reach by about 15%. Evidently reaching with one's hand provides feedback that things are farther away than they appear. This may have caused people in prior experiments who reached with their hand after each trial to elevate their estimates on subsequent trials. Rather than an effect of intending to reach with a tool, differences may have reflected an effect on the hand condition.

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33.441 Metric visual information about distance entails informational units

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Introduction: Mon-Williams and Bingham (2007) showed that perception must be calibrated to yield accurate targeted actions and argued that metric units of visual information about target distance are mapped to the unit of the targeted action. The implications of this mapping have not been systematically described and investigated. If it is the size of the units that is calibrated, then subsequent change of the units should alter the slope of a relation between actual and perceived distance as revealed by targeted actions. Methods: Sixteen participants performed an open loop action, moving an unseen marker using a rope and pulleys to visible targets (placed between 50 and 250cm from the participant) in the dark. In Experiment 1, participants binocularly viewed a point light at eye level and the binocular unit, inter-pupillary distance (IPD), was altered by 1.6cm. In Experiment 2, participants monocularly viewed phosphorescent targets on a phosphorescent textured surface with the monocular unit, eye height (EH), at 24cm or 48cm. Participants were calibrated to a certain IPD/EH, and then tested with altered IPD/EH. Performance before and after unit change was compared. Results: Linear fit of responses to target distances yielded significant slope change ($p < 0.02$) with changing EH and IPD units. When participants were tested with larger IPD after calibrating to smaller IPD, the slope was 0.93; conversely, when tested with smaller IPD after calibrating to larger IPD, the slope was 1.19. When participants were tested with large EH after calibrating to small EH, the slope was 1.04 and when tested with small EH after calibrating to large EH, the slope was 1.39. Responses using consistently large or small calibrated units were not different in either monocular-EH or binocular-IPD case. The results confirmed that perception of metric distance in depth is specified by sources of information that entail metric units.

33.442 Intrinsic scaling of reaches-to-grasp predicted by affordance-based model: Testing men and women with large and small grip spans

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Reaching-to-grasp has been extensively studied to discover the functional timing of the movements, but, not the spatial scaling relations. However, Mon-Williams and Bingham (2005; submitted) discovered the affordance properties of objects that determine the spatial structure of reach-to-grasp movements. Using these findings, they formulated a model that contained a single free parameter and other variables that were determined by object, maximum object extent (MOE), and actor, maximum grip span (MGS), properties. In this experiment, we investigated the generality of this model by assessing the spatial structure of the reaches-to-grasps of participants with greatly differing maximum grip spans: males with large and small grip spans (18.4, 14 cm) and females with large and small grip spans (16, 12.4cm). Participants reached, at a medium or fast pace, for objects that systematically varied in object width (3, 5, 7cm) and contact surface size (1, 2, 3cm), and thus in MOE, while taking care not to move the objects. The model predicts that the margin of safety at the time of maximum grasp aperture (MGA) for medium and fast paced reaches should be 24% and

34% of the available span (which equals MGS-MOE), respectively. The average safety margin at MGA for all males and females with large grasp spans replicated the model predictions (large-spanned males: 22%, 32%; small-spanned males: 25%, 33%; large-spanned females: 24%, 32%). These results confirm the affordance-based model in predicting the spatial structure of reaches-to-grasp. The safety margins for females with small grasp spans were somewhat different (37%, 45%). This may reflect proximity to a critical action mode boundary for them. Results for terminal grasp aperture and object width were similarly consistent with the model and previous results.

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33.443 Learning to stop looking at the task in hand

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Many surgeons have difficulties transitioning from open to laparoscopic surgery. A common report is that surgeons (particularly novices) look at their hands when performing laparoscopic operations, rather than fixating on the screen (Law et al, 2004). Skilful movements require feedback information (typically visual) to make online corrections, but if there is a mismatch between the direction of hand motion and the ensuing action then the system needs to adapt. By adulthood, individuals have become proficient in visually guiding their hand to a target, but it seems that they are also adept at guiding their hand when visual feedback is absent or distorted (e.g. using a mouse to control the movement of a visual cursor on a computer screen). We hypothesised that if manual control is dominated by visual-feedback about hand-position then distorted visual-feedback would be most problematic when the hand is visible ('visual capture'). We tested our hypothesis by studying the rate of adaptation to distorted visual-feedback in two separate groups ($n=44$). One group (indirect) were prevented from seeing their hand and viewed the display on an external monitor. The other group (direct) viewed their hand and the visual display directly. The task involved carrying out a series of aiming movements using a handheld stylus on a tablet-laptop. Both groups completed baseline trials and then two distorted visual-feedback blocks (30° and 60° rotation, counterbalanced) before being tested at 45° the following day. We used movement duration as an index of learning. The results revealed group differences, with the indirect group adapting more readily to the distorted feedback. These results show that additional information about hand-position actually impairs adaptation to distorted visual feedback, which suggests that surgeons need to learn to fixate the screen rather than their hands during laparoscopic operations.

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33.444 The Poggendorff Illusion Fools Perceptions and Various Actions

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Numerous studies designed to test Milner and Goodale's (1992) two-stream model of visual processing have used visual illusions as stimuli. The general claim is that finding a dissociation between perception and action in responses to an illusion provides evidence for the operation of two independently operating streams. The present study used the Poggendorff illusion to investigate the perception-action dissociation (see also Melmoth, Tibber, Grant and Morgan, 2009). A novel stimulus configuration was used, consisting of a rectangular bar, a line that intersected one (long) side of the bar, and a column of numbers to the other side of the bar. In separate experiments, participants were required to project (mentally or by various hand movements) the intersecting line beyond the other side of the bar to the number column. Figures were presented on legal sized paper tacked up at eye level; when required, movements were made directly to the paper. Effects of the illusion were assessed based on projected lines' degree of misalignment from the original. Across experiments, the oft-reported dissociation between perception and action in responses to visual illusions was not found. The apparent effect of the Poggendorff illusion on actions was consistently as great—or greater—than its effect on perceptual judgments. This was also true for an altered version of the figure in which the rectangle was removed altogether and just the line and number column remained. The prevalence of the Poggendorff illusion's affect on actions does not support the two-stream model. Alternately, this suggests that the locus of this illusion's effect is early in visual processing before the two streams have diverged (see Dyde and Milner, 2002).

Scene perception: Memory and context

Sunday, May 8, 8:15 am - 12:15 pm

Orchid Ballroom, Poster Boards 445 - 458

33.445 Decoding objects undergoing contextual violations

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Contextual violations have long been known to cause deficits in object detection and recognition (Biederman, et al. 1982). Incongruent objects attract earlier and longer eye fixations (Underwood & Foulsham 2006) and evoke stronger ERPs (Mudrik, Lamy, and Deouell 2010), suggesting that the brain rapidly marshals additional resources to aid in processing unexpected objects. Despite a wealth of psychophysical results on context, cortical models of contextual facilitation are still speculative (Bar 2004). In this study, we use MVPA methods with fMRI data to explore the effects of context on neural representations. MVPA allows us to assess the quality of the representation as opposed to simple changes in overall activity afforded by more traditional fMRI analysis methods.

First, we showed that a classifier trained using lateral occipital complex (LOC) responses to isolated boats and cars generalized (achieved above-chance decoding accuracy) to the same objects placed in scenes. We then presented these objects in scenes that violated a semantic relationship (e.g. a boat sitting on a city street) and/or a geometric relationship (e.g. a car flying over a city street). Although these violations had similar slowing effects on reaction time in a detection task, they had very different impacts on object representations in LOC. Decoding performance decreased to chance when a geometric relationship was violated, but actually increased when a semantic relationship was violated. These results suggest that context not only impacts object detection but influences object representations in complex ways, presumably via interactions with other cortical areas. We explore decoding rates from other ROIs to further explore these contextual interactions.

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33.446 Scene categorization after priming/adaptation to amplitude statistics

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The visual system is able to rapidly and accurately categorize natural scenes. Whilst diagnostic information for categorization is considered to be contained mainly in the localized phase structure of an image, there is some debate as to the potential role of amplitude spectra information. For priming (Guyader et al., 2004) and adaptation (Kaping et al., 2007) studies, the presentation of amplitude information prior to image categorization has been shown to shift observer judgements, suggesting an influence for amplitude statistics in image categorization. We created prime/adaptation stimuli by averaging the amplitude spectra of a large number of natural or man-made stimuli. These images (with randomized phase information) were presented for durations ranging between 50ms and 4s, prior to the brief presentation of a test stimulus (14ms). Test stimuli consisted of averaged amplitude spectra of a pair of images, one natural and one man-made. Phase information for a test image was a blend between the two single images, from 20% natural, 80% man-made to 80% natural, 20% man-made. Observers classified each test image as natural or man-made. Our observers showed a shift in their natural/man-made category boundary following longer presentations of the adaptation stimulus, yet limited priming effects. These results indicate that amplitude information may be of limited importance to image classification.

33.447 Contextual associations facilitate long-term memory of visual details in barely seen pictures

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Objects typically appear within cluttered scenes, where they compete for limited processing resources. Visual contextual regularities may streamline object recognition, by reducing input complexity and by increasing scene

coherence. What is the nature of memory-encoding of object-to-object contextual associations during a brief visual glance? Ample research has suggested that under very rapid viewing conditions only the 'gist' of a scene is grasped, while little visual detail is accessed and retained in long-term memory. In the present research we investigated whether contextual associations may enhance memory of visual details, even when objects are merely glimpsed. Participants viewed pairs of contextually-related and unrelated objects (e.g., a kettle and a mug; a shovel and a vase, respectively), presented for an extremely short exposure duration (24 ms, masked). Subsequently, participants performed a memory-recognition test, in which one of two objects within a pair was replaced by a novel object from the same basic category. Participants differentiated old objects from novel object exemplars, while these were presented with their original counterpart pair object. Results demonstrated higher levels of correct recognition for contextually-related than for unrelated object pairs (recognition rates in the latter did not differ from chance level). Furthermore, when object stimuli in the recognition test appeared alone, i.e., without a corresponding pair object serving as a memory-retrieval cue, results remained virtually identical. Namely, memory for specific visual details remained higher for objects initially appearing within contextually-related, than unrelated, object pairs. These results strongly suggest that while contextual information may provide a coarse 'schema' that enables memory of meaningful visual input (i.e., the 'gist' of a scene), it also enhances the representation of specific visual details in the scene, even within a mere glimpse.

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33.448 Reducing expectations: Is an extension of current boundary extension theories needed?

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Boundary extension is a phenomenon in which people remember seeing more of a recently-viewed image than was actually shown. Typically, close-angle images produce greater amounts of extension than wide-angle images, however, images must be perceived as having a continuous, yet truncated, view of the world. Current theories of boundary extension suggest the phenomenon involves a source monitoring error between mental representations created by sensory information present in the image and representations containing amodal information based on perceptual expectations. If this is the case images/scenes with reduced expectations to amodally continue should not produce or minimally produce boundary extension. In the current study we tested this idea by removing a number of factors thought to contribute to amodal continuation including familiarity, texture gradients, and occlusion information. We did this by using 2-D abstract shapes on random-dot backgrounds where the backgrounds were either occluded by the border or not and where the objects occluded the random-dots or not. We found boundary extension occurred in all conditions created to minimize amodal continuation. These results suggest modification of current boundary extension theories may be necessary to incorporate the present findings.

33.449 Event Extension: Event Based Inferences Distort Memory in a Matter of Seconds

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We tend to think and talk about continuously unfolding time lines in discrete terms. Imagine, for example, a series of events that consists of picking up a pen, taking the cap off and signing one's name on a piece of paper. Even though time progresses continuously, we typically conceptualize this as a series of three discrete events with clear temporal boundaries. Untrained observers have been shown to spontaneously create discrete "event files" like this that can have powerful effects on memory of and attention to ongoing activities (Zacks et al., 2006; Swallow et al. 2009). Here, we present novel evidence that the process of creating an event file through causal bridging inferences (Haviland & Clark, 1974) can distort perceptual memory just seconds after the perception of the event, in a manner reminiscent of boundary extension in scene perception (Intraub 1993). 54 adults watched videos of a person throwing (or launching) an object but that were missing the moment of release (or collision). Roughly ten seconds afterwards, subjects falsely reported seeing the moment of release when it was highly implied by subsequent video footage but did not do so when the release was not implied. Causal implications were disrupted

either by replacing the resulting flight of the ball with irrelevant video or by scrambling event segments. Subjects in the different causal implication conditions did not differ on false alarm rates for other unseen pictures that could have appeared in the event, nor did they differ in general recognition accuracy. Thus the increased false alarms were specifically limited to the moment of release and only occurred in those subjects for whom the release was causally implied. These results suggest that as people perceive events, they generate rapid conceptual interpretations that can have powerful effects on how events are remembered and encoded.

33.450 **More Space Please! The effect of clutter on Boundary Extension**

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Memory for scenes consistently includes expanse that was not actually viewed but that was likely to exist outside the boundaries of the view. This distortion, Boundary Extension (BE), has been ascribed to the activation of mental layout representations during scene perception. The occurrence and the degree of BE could, therefore, provide insight about the visual information that influences scene processing. The current study examined the influence of clutter in real-world scenes on memory for scene expanse. Clutter was conceptualized as the amount of perceptual detail present in a scene. Uncluttered scenes (e.g., sandy beach, open field) can arguably be extended more easily; the layout beyond the boundaries of the view would be more predictable than in more cluttered scenes (e.g. rugged rocky shore, busy city street). However, if the extrapolation that leads to BE is done in order to provide a broader context for understanding and perhaps interacting with the scene, cluttered scenes may require larger extrapolation as they may be more perceptually challenging. Participants viewed 32 pictures of real world scenes; half were relatively cluttered and half were relatively uncluttered. Pictures from the same semantic categories were used in both conditions. Participants studied each picture (15s) and then judged how cluttered it was. (Participants' clutter ratings confirmed the a priori categorization of scenes). This presentation was followed by a forced-choice memory test using four distractor pictures depicting from 20% larger to 20% smaller expanses. More BE was obtained for cluttered scenes than for uncluttered ones. Generally, these results demonstrate again the influence of scene layout on BE. More specifically, the results suggest that the amount of information in a scene influences the degree to which viewers need to predict the broader spatial context of the partial view they see.

33.451 **Threat is separable from stimulus negativity in visual scenes**

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All existing theories assume that the basic affective distinction of a stimulus is its positivity/negativity value. The implicit assumption of these models is that negativity and threat are functionally equivalent qualities of a stimulus. Our study challenges this assumption. Because efficient recognition of threat promotes survival, we hypothesized that the potential of harm is extracted automatically as part of stimulus meaning. We predicted that observers would discriminate between images that were merely negative from those that were also threatening. To test this hypothesis, we obtained negative and neutral scenes containing similar potential threat objects. We subdivided these stimuli into four a priori conditions: 1) direct threat (i.e., a threat to one's person); 2) indirect threat (i.e., a threat to someone else); 3) past threat (i.e., a threat that is no longer viable); and 4) neutral (i.e., no threat). We then asked three groups of observers in a between-subjects design to view and rate the scenes in response to one of the following questions: Group 1) "How much harm could be about to occur to you?"; Group 2) "How much harm could be about to occur to someone else?"; Group 3) "How much harm has already occurred to someone?". Each group responded to only one of the questions on a scale of 1 to 6 and was unaware of the other questions, or the condition to which the scene belonged. We found that each group classified the three types of negative affective scenes in a highly distinct and consistent pattern (scene type x group interaction $F_{2,4} = 20.7, p=0$), assigning the highest rating to the relevant a priori stimu-

lus condition. We conclude that observers are exquisitely sensitive to the threat context, and demonstrate that they can clearly make a distinction between levels of threat and general negativity.

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33.452 **The Impact of Scrambling the Order of Episode Components on Perceived Events and Recognition Memory for a Picture Story**

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Story Grammars (Mandler & Johnson, 1977; Thorndyke, 1977) hierarchically organize narratives into separate structures. One such grammar (Baggett, 1979) parses stories into separate episodes, which are divided into three components: the exposition, complication, and resolution. The exposition introduces the character and setting, the complication presents a goal, and the resolution shows the character achieving the goal. Our previous research examined the effect of scrambling these components on recognition memory for a picture story. We hypothesized that scrambling the components would increase the number of perceived events, producing better memory at the event boundaries (Hanson & Hirst, 1989; Lassiter et al., 1991). However, we found no difference in recognition memory between the scrambled versus normal episodes. This study tested one explanation for this finding, namely that scrambling did not increase the number of perceived events, by measuring viewers' event segmentation behavior.

We selected six episodes from the film *The Red Balloon*, with each episode component composed of 4 pictures. Pictures were presented for two seconds (ISI = 1 sec). Participants viewed either scrambled or normal episodes and pressed a button whenever they perceived a new meaningful activity. Prior to the experiment, participants practiced identifying events in a short video of folding laundry, a picture story version of it, then two picture story episodes from *The Red Balloon* not used in the experiment.

The results showed that the mean number of button presses did not differ between the scrambled and normal conditions. However, scrambling significantly increased the mean button presses for the first pictures in the exposition and resolution, suggesting viewers perceived new events there due to decreased story coherence. Interestingly, this increased perception of new events for these pictures did not produce better recognition memory for them, contrary to predictions from previous research (Lassiter et al., 1991; Zacks, et al., 2007).

33.453 **The effect of consistency on scene short-term memory**

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The term scene consistency refers to the probability that a given object naturally appears in a given context. For inconsistent object-context pairs this probability is low (e.g. a bird that flies underwater). Categorization and naming is faster and more accurate for consistent pairs, while fixation and detection of orientation changes is faster for inconsistent pairs. The present study examines the role of scene consistency in scene short-term memory in a change detection paradigm. Experiment 1 demonstrates that changes are detected more accurately when scene consistency changes from probable to improbable (or from improbable to probable) than when consistency does not change. However, a consistency-change can also be interpreted as a between-category change, which might be more easily detected than within-category changes. To test this alternative explanation, we presented objects and backgrounds separately in experiments 2 and 3. Results showed that participants detected within-category changes and between-category changes equally well when objects and backgrounds were presented in different frames (experiment 2). However, they detected between-category changes better than within-category changes when objects and backgrounds were presented in the same frame (experiment 3). In experiments 4 and 5, we conceptually replicated experiments 1 and 3 with monochrome stimuli instead of chromatic ones. In summary, this study demonstrates that scene consistency might play a role in scene short-term memory. However, the effects of scene consistency- and category-changes on change detection performance were not fully disentangled. Future research might differentiate between these two possible interpretations of our results.

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33.454 Object Orientation Influences False Memory for the Shape of a View

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Intraub's (2010) multisource model of scene perception suggests that representations of scene views incorporate both bottom-up and top-down input. We examined the contribution of bottom-up information to memory for unseen layout beyond the edges of a view (boundary extension; BE) by testing whether the way an object fills the space of a view influences BE. Stimuli were photographs of overhead views of scenes showing a single object against a natural ground surface (e.g., a hammer on gravel); all stimulus views were square. Objects filled views in one dimension but not the other (e.g., a screwdriver, flashlight). Observers (N=39) viewed a sequence of 12 close-up views for 15 s each (views alternated with 1-s masks); half the objects were oriented vertically; the other half horizontally. All objects appeared both horizontally and vertically across participants. Horizontal-vertical viewing information was made comparable by placing square frames in front of monitors; stimuli were viewed within a square cutout in the frames' centers. After viewing the 12-picture sequence, observers were instructed to adjust each picture's four view-boundaries to recreate the original view (initial border placement in test views was identical to that in stimulus views). An increase in the overall area of views would indicate BE. In addition to finding significant BE across observers (mean increase in area - vertical objects: 17.2%; horizontal objects: 14.9%; both ps <.001), we found that object orientation influenced BE: for both object orientations, significantly more BE occurred along the object's longer axis (both ps <.001). In addition, for vertical objects, significant BE was found along both object axes (width: 5.1%; height: 10.2%); for horizontal objects, significant BE was found only along the longer axis (width: 12.2%; height: 1.1%). The results suggest that BE is influenced by how objects fill the space of a view, with extension along the pictures' horizontal and vertical axes being differentially affected by object orientation.

33.455 Visual Long-Term Memory of Scenes is Vulnerable to Bubbles

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Previous research has shown that visual long-term memory (VLTm) has large capacity (Shepard, 1963; Standing et al., 1970, 1973) and can store rich details (Brady et al., 2008; Konkle et al., 2010) for both object images and scenes. Here we investigated the fidelity of VLTm by occluding images with "bubbled" masks that had various degrees of coverage. The bubbles were comprised of six circles with varying sizes and positions, and only the region inside these "bubbles" was visible. Participants viewed 228 scenes for 20 minutes, followed by a 15 minute Ospan task to measure working memory capacity, and then completed a series of forced-choice memory tests for the previously viewed images. Across all experiments, there was no correlation between performance on the VLTm task and Ospan score. Experiment 1 used bubbled scenes (coverage: 20%, 40%, 60%) for both study and test and subjects were asked to remember the specific scene/bubble combination. At test, subjects performed a four-alternative-forced-choice task with the foils being old-Picture-new-Bubbles, new-Picture-old-Bubbles and new-Picture-new-Bubbles. Although subjects correctly choose the target on 41% of the trials (above chance, $t(9)=4.8, p<.01$), they false alarmed to the foils on 26%, 17% and 17% of the trials, respectively. These data suggest that subjects are more sensitive to the scenes than the specific bubbling patterns. There was no effect of the degree of bubbling coverage ($F < 1$). We next asked whether bubbling would impair memory when the task was to remember only the scenes. Experiment 2 used non-bubbled scenes for study and bubbled scenes (coverage: 0%, 30%, 60%) for the test. Although there was a significant drop in accuracy for 60% coverage condition, performance was still above chance. Together these results suggest that memory for scenes are resilient but not impervious to occlusion.

33.456 What is the speed of visual recognition memory?

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Investigations into the neural correlates of recognition memory suggest that there are two major sources of "recognition signals", the rostral end of the visual ventral stream (rVVS) and the hippocampus. The rVVS is thought to support familiarity, a rapid context-free recognition signal, while the hippocampus is thought to support recollection, a slow context-rich recognition signal. In accordance, analyses of surface and intracerebral evoked potentials show a difference between familiar and unfamiliar stimuli starting ~250 ms in the rVVS, and ~320 ms in the hippocampus. It remains controversial whether the rVVS can support recognition memory alone. If we add ~130 ms, the minimum time required to generate a motor response (Kalaska et Cramond, 1992 in the macaque), a response could occur around 380 ms based on the VVS and around 450 ms based on the hippocampus. To investigate the minimal time required for recognition memory, we designed a specific experiment to constrain participants to answer as quickly as they could. We used a Go/No-Go task with a response deadline 600 ms after stimulus onset (boosting speed) and an audio feedback for each response (boosting accuracy). We show that recognition of famous among unknown faces (120 targets/120 distractors) starts at 390 ms (min RT, hits different from false alarms ($p<0.05$) for at least 2 consecutive bins of 10 ms, N=8 participants). We ran the same experiment with two other categories of stimuli (abstract patterns and objects). Recognition of these stimuli was preceded by a self-paced study phase. Minimal RT for the abstract patterns and objects were 420 ms (N=15) and 400 ms (N=14), suggesting furthermore that verbalization and semantic content does not interfere with speeded visual recognition. These results support the idea that recognition can be based on the rostral visual ventral stream alone, in particular for rapid recognition.

33.457 Mental representation of compositions in paintings is based on their perceptual similarities

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Recent studies have found that art works and human vision share some basic characteristics, such as statistical regularities (Graham & Field, 2007), motion (Kim & Blake, 2007), and lightness perception (Cavanagh, 2005). Perception of spatial relations is another important visual ability that artists have long been employed in their art works as composition. We investigated whether people utilize compositional information when they see paintings and if compositions are, indeed, mentally represented. In order to see whether people make use of the compositional information, Experiment 1 tested the hypothesis that paintings with similar compositions would interfere with target detection in a rapid serial visual presentation paradigm. The stimuli were 495 Renaissance paintings classified in advance into 6 different compositions based on experts' ratings. We found that target detection performance significantly decreased when the composition of the target image was consistent with the distracters compared to when they were inconsistent, suggesting the interference by the similar compositional information. Experiment 2 was conducted to examine whether paintings were mentally represented according to their compositions. If the interference effects found in Experiment 1 were due to representation of compositions, paintings with perceptually similar compositions should be closely placed in mental space. Participants learned to associate arbitrary numbers assigned to 30 paintings. The frequency of errors was measured to construct confusion matrices, which were then analyzed through multi-dimensional scaling. As expected, the paintings with the same composition were grouped together with significantly shorter psychological distances in a two-dimensional space. These results suggest that compositions in paintings are utilized and represented according to their perceived similarities. Our research supports the view that artists' creation of visual works is based on their active exploration of how we see the world, and provides a possible link between human vision and aesthetic preference.

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33.458 Integration without awareness: expanding the limits of unconscious processing

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Human conscious awareness is commonly seen as the climax of evolution. However, what function – if any – it serves in human behavior is still debated. One of the leading suggestions holds that the cardinal function of conscious awareness is integration across numerous inputs and levels of analysis – including the multitude of features and objects in a complex scene – into a unified, coherent, and meaningful perceptual experience. Here we demonstrate, however, that integration of objects and their background scenes can be achieved without awareness of either. In a group of human observers, complex scenes including incongruent objects were faster than normal scenes to escape perceptual suppression induced in a binocular rivalry setting known as Continuous Flash Suppression. We conclude that visual awareness is not needed for object-background integration or for processing the likelihood of an object to appear within a given semantic context, but may be needed for dealing with novel situations.

Attention: Capture

Sunday, May 8, 8:15 am - 12:15 pm

Vista Ballroom, Poster Boards 501 - 516

33.501 On The Precision of Attention Sets: Effects of Distractor Probability and Temporal Expectations on Contingent Capture

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The contingent spatial blink paradigm developed by Folk, Leber, and Eggh (2002) reveals a surprising lack of precision when it comes to our ability to maintain attention goals (sets). A completely irrelevant distractor sharing the color of a target letter in an RSVP (rapid serial visual presentation) stream produces a substantial attention capture effect, even when this distractor is distant from the RSVP stream, and the target's spatial location is central and constant. We examined whether the precision of attention sets can be improved by manipulating participants' expectations. In one experiment, the probability of the target-color-matching distractor was manipulated between groups to appear frequently or infrequently. We hypothesized that participants who encountered the peripheral distractor more frequently would develop a more precise attention set encompassing only the target's location, resulting in less capture. Consistent with this hypothesis, capture effects were smaller when the distractor's occurrence was frequent. We also manipulated the probability of the distractor occurring at a specific location, but found that consistent distractor location did not elicit less capture compared to when the distractor had a chance of occurring at four possible locations. Finally, we examined the possibility of training participants to adopt a temporally narrow attention set. Training involved searching for a target that occurred in the RSVP stream randomly (broad temporal window), or searching for a target that always occurred in the middle of the RSVP sequence (narrow temporal window). However, when participants were transferred to a block of trials in which the target always occurred in the middle of the stream and distractors could appear before or after it, capture effects were equivalent across groups. The present study suggests that experience (i.e., distractor frequency) can modify attention sets, but the precision of attention sets is largely unaffected by temporal and spatial expectations.

33.502 Is attentional capture modulated by task difficulty? An N2pc study with visual search of repeated and changing targets

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Attention may be guided by intentions in a top-down fashion or may be driven by salient stimuli in a bottom-up fashion. Using event-related potentials (ERPs), Hickey et al. (2006) demonstrated that salient colour singletons

catch attention without any intention to attend to colour, supporting the notion of bottom-up control. However, using similar displays, by Schubö (2009) did not observe that irrelevant colour singletons capture attention. We tested the idea that this discrepancy was due to the difference in task difficulty between the two studies. As in the previous studies, we measured ERPs and focused on the N2pc component as a measure of attentional deployment. Similar to Hickey et al. (2006), our subjects searched for a shape singleton whose identity varied unpredictably from trial to trial (mixed target condition). Additionally, we ran a condition similar to Schubö (2009) in which target identity remained constant in a block of trials (same target condition). Our behavioural results showed that the same target condition was performed significantly faster than the mixed target condition, confirming a difference in task difficulty. Additionally, responses were slowed by the presence of an irrelevant colour singleton in mixed and same target conditions, but interference was larger in the mixed than in the same target condition (consistent with Pinto et al., 2005). Further, we did not replicate an N2pc to the colour singleton that was reported by Hickey et al. However, we found a significant enhancement of the N2pc component in the same target condition compared to the mixed target condition. The N2pc enhancement was observed for different positions of the colour singleton (same side, opposite side or vertical). Based on these findings, we conclude that the N2pc may index mechanisms involved in identifying and localizing relevant stimuli through enhancement of their features.

33.503 The effect of context on oculomotor capture: It's better not to think about it

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An abundance of research has demonstrated that attention is captured by the appearance of abrupt onsets in visual displays. Abrupt onsets capture both covert and overt attentional systems and are thought to do so largely, if not entirely, in a bottom-up stimulus driven fashion, independent of any top-down attentional factors. However, Kramer et al. (2000) demonstrated that the magnitude of oculomotor capture could be influenced by participants' awareness of the abrupt onset. By making the abrupt onset more salient, younger individuals demonstrated less oculomotor capture than when the abrupt onset was less salient. This finding highlights the possibility that the magnitude of oculomotor capture may be influenced by contextual factors. In the present study, awareness was manipulated via task instruction while stimulus properties were kept consistent across all conditions. Prior to completing a traditional oculomotor capture task, participants were either a) informed that an onset would appear on some trials, b) informed of the abrupt onset and instructed to actively avoid looking toward it, or c) were not informed of the presence of the abrupt onset. Results provide evidence that the instructions influenced the magnitude of oculomotor capture. Those instructed to actively avoid the abrupt onset were worse at doing so than those simply informed of its presence. Those not told of the abrupt onset fell between these two extremes. Consistent with the view that abrupt onsets capture attention and the eyes in a bottom-up manner, oculomotor capture was observed in all conditions; however, the present findings highlight the potential importance of context in modulating this effect.

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33.504 Capturing attention without onset transients

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An object appearing abruptly in an unoccupied location captures attention. There are two possible explanations: (a) the transients that accompany the abrupt onset of the object cause attention to be deployed at the site of the onset; (b) as the onset represents a new entity it behooves the visual system to discover immediately aspects of the new object. Using a visual search task designed for inefficient search, we addressed the question whether onset transients are necessary for attentional capture. Observers first saw a display containing several static placeholders. A mask made up of random lines was then applied over the display. Next, the mask disappeared, revealing the search letters occupying the same locations as the placeholders. Search-set size was manipulated. To test the new object hypothesis, an additional object was inserted into the display behind the mask, making the objects' onset transients invisible. The critical comparison was between the condition where the additional object was a target, and where it was a distractor. If the new object succeeded in capturing attention, search laten-

cies should be independent of set size if the additional object was a target. But, if onset transients are crucial, the new object, added without its onset transients visible, should fail to capture attention. The search function, therefore, would have a positive slope. But for this paradigm to constitute an effective test of the new object hypothesis, the observer must be able to establish correspondence between the pre-mask, and post-mask, objects. Only then will the new object stand out as the entity for which there was no correspondence to the pre-mask set. We show in these experiments that when conditions favored encoding of the pre-mask objects, the additional object successfully captured attention even when its onset transients were invisible. Otherwise, attentional capture by the additional object failed.

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33.505 Contingent attentional capture depends on stimulus properties

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The issue whether attentional capture is determined by top-down control settings or it can be purely stimulus-driven remains unsolved. We have shown previously that only a visual onset, but not color, can capture attention in a purely stimulus-driven fashion (Yeh & Liao, 2008, 2010). Here we propose that whether top-down control settings take the determinative role in attentional capture depends on stimulus property. Visual onset is unique in capturing attention due to its transient property that can be escaped from the modulation of top-down controls. In contrast, a sustained color signal which allows more time for top-down signal to exert its effect captures attention only when the color is contingent with top-down control settings. We test this hypothesis by adopting a spatial cueing paradigm, in which two types of cues (onset and color) were followed by either one of the two types of targets to examine whether the cue captures attention depending on its contingency with the target-defining feature as well as the stimulus property. To further explore the underlying mechanisms of attentional capture by onset and color, we manipulated the cue-to-target stimulus-onset-asynchrony (SOA) to examine how the capture effect varies with time. Results showed that the onset cue captured attention regardless of the target type in short but not long SOA conditions. In contrast, the color cue captured attention only when the target was defined by color, and the capture effect lasted until long SOAs. Taken together, the results suggest that attentional capture by onset can be purely stimulus-driven whereas attentional capture by color is contingent on top-down control settings. We suggest that different underlying mechanisms are responsible for attentional capture by onset and color respectively, with the former resulting from exogenous orienting and the latter, feature-based attention enhancement.

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33.506 Motion refresh rates determine how continuous and starting motion captures attention

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In a recent study von Mühlenen and Sunny (2010, *Journal of Vision*) showed that motion onset capture attention only when motion was jerky (refreshed at 8 or 17 Hertz), but not when it was smooth (33 or 100 Hertz). They also showed that simple flicker (without motion) did not account for this result, ruling out explanations that put capture down to the continuous stream of luminance transients produced by jerky motion. Thus, it remains unclear why the onset of jerky motion captures attention. In this study we build on von Mühlenen, Rempel, & Enns (2005, *Psychological Science*) and suggest that the lower motion refresh rate delays the perceived motion onset, turning it into a temporally unique event. According to von Mühlenen et al. (2005) any change can capture attention provided that it occurs during a period of temporal calm, where no other display changes happen. Experiment 1 used the same paradigm and refresh rate manipulation as von Mühlenen and Sunny (2010), except that one item was now continuously moving from the beginning of the trial. The results showed no capture for continuous motion irrespective of whether motion was jerky or smooth. This means, attention is not captured by jerky motion per se, but by the onset of jerky motion. Experiment 2 used again motion onset as in von Mühlenen and Sunny's study. However after the first displacement, which occurred either after 120, 60, 30, or 10 ms (equivalent to the 8, 17, 33 or 100 Hz motion

refresh rates previously used), all moving stimuli continued with smooth 100-Hz motion. The results showed essentially the same pattern as in von Mühlenen and Sunny's experiment, with significant capture only in the delayed (120 and 60 ms) displacement conditions. Both experiments support von Mühlenen et al. (2005) unique-event account.

33.507 Does Hand Position Affect Attentional Capture by a Salient Distracter?

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Past studies have found specialized bimodal neurons, which integrate visual and tactile information in the space near the hand (Graziano & Goss, 1993). More recently, researchers demonstrated that these bimodal neurons influence early perceptual processes (Cosman & Vecera, 2010) and attentional prioritization of space (Reed et al, 2006). However, neither of these two studies examined how bimodal neurons interact with the saliency of the stimuli in the display. To answer this question, we investigated salience-based attentional capture by an irrelevant color singleton (Theeuwes, 1992). Participants searched for a shape singleton with an irrelevant color singleton present on half the trials. In addition, participants held their left hand near the display on half the trials and they held their right hand near the display on the other half. Our results confirmed past findings by showing, in distracter absent trials, faster reaction times when the target was near the hand than when the target was far from the hand. In addition, we found distracters near the hand captured attention significantly more than distracters far from the hand. Importantly, hand position affected capture by a color singleton more than hand position facilitated attention to the target shape singleton. Also, when a distracter was present in the display, response times to a target near the hand were no different from response times to a target far from the hand. Our results suggest that the attentional effects of hand position interact with the saliency of the items in the display.

33.508 Attentional Capture and Aging: Increased Salience

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Attentional orienting is the consequence of a finely tuned interplay between top-down (goal directed) and bottom-up (stimulus-driven) attentional allocation. While the contribution of each type of orienting is well understood in young adults, the degree to which this interplay is affected by aging remains poorly understood. In the present set of three experiments we investigated whether contingent capture, constrained by top-down control, is affected by aging to a lesser extent than the singleton capture (constrained by bottom-up control). Young and older participants viewed a central rapid serial visual presentation (RSVP) stream in which a target letter was either defined by a specific color (e.g., green) or was defined by the virtue of being different from other central letters (e.g., any colored letter embedded among black central letters). On critical trials, an irrelevant colored singleton and three neutral distractors appeared in the periphery. On half of the trials the distractor matched the color of the target while on the other half of the trials the distractor was of a non-matching color. Capture was assessed by measuring the degree of interference in processing the central target letter as a function of whether the distractor matched the target color. We observed that older participants exhibited hypercapture in the contingent capture experiment, such that both the matching colored distractor as well as the non-matching colored distractor interfered with central target processing. This result was different from that observed in young adults who showed capture by a matching colored distractor exclusively. These results suggest that the top-down goals constraining bottom-up attentional orienting in a normal functioning system are compromised with aging, possibly indicating targeted atrophy of the superior parietal lobe with aging.

33.509 The Time Course and Nature of Attentional Disengagement Effects

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Recent work has highlighted how, during visual search, both irrelevant and relevant information within the focus of attention can influence attentional disengagement and the location of subsequent deployments of attention (Boot & Brockmole, 2010; Born, Kerzel, & Theeuwes, 2010; Brockmole & Boot, 2009). Participants in our studies began search by fixating an irrelevant item. Even though this item was never the target, saccades away from

it were slowed when it shared the same color as the target. In a new series of experiments, we explored this attentional disengagement effect in depth. Specifically, we examined the time course of this effect, how the persistence of the item within the focus of attention influences disengagement, and whether similar effects could be observed when participants searched for targets defined by shape instead of color. Robust disengagement effects were observed when the color of the irrelevant fixated item matched the color of the search target, but only if the fixated item remained onscreen. Disengagement costs first appeared when the irrelevant item matched the target item approximately 70 ms before the search display, and grew stronger as the irrelevant item and search display approached simultaneous presentation. Non-persistent items produced no cost in terms of latency, but did bias eye movements to distractors that shared their features. This effect decreased as simultaneous presentation was approached. Thus, dissociable effects were observed on saccadic direction and latency. Furthermore, when participants searched for a target defined by shape, disengagement was delayed when this same shape was presented within the focus of attention, although disengagement effects were much smaller. Experiments confirm and extend findings suggesting a research focus not just on features that pull attention to a location, but also a focus on the features that hold it there as well. Both processes are critical determinants of visual processing.

33.510 Active suppression of attention after the completion of perception

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After attention has facilitated perception at a location, is it then reset by an active suppression mechanism or does it passively fade away? The present study investigated this issue by using ERP measures, which can track attention after the completion of a perceptual task without the addition of a secondary task. In Experiment 1, subjects searched for a target with a defined color at a peripheral location in arrays of three objects. We found that the target elicited an N2pc component (a measure of attentional deployment) followed by a Pd component (a measure of attentional suppression). In Experiment 2, the target was again defined by color, but now presented at the central location. When a distractor containing the target color was presented at a peripheral location, it also elicited N2pc followed by Pd. Experiment 3 confirmed that the Pd effect is associated with active suppression by showing its correlation with behavioral performance. In Experiment 4, a to-be-attended location (left or right) was cued on each trial, and the target was an object with a defined color at the attended location. We found P1 enhancement (a measure of spatial attention) followed by Pd for the target at the attended location, N2pc followed by Pd for a distractor containing the target color at the unattended location, and P1 enhancement followed by Pd for a non-target at the attended location. These results suggest that attentional enhancement is subsequently suppressed by active suppression mechanisms. This suppression may enable us to reset increased processing weights and disengage attention, leading to efficient preparation for upcoming information.

33.511 Objects approaching your avatar engage attention

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Intuitively, attention is captured by objects that rapidly approach us. Indeed, experimental evidence has shown preferred processing of looming stimuli. According to the behavioral urgency hypothesis (Franconeri & Simons, 2003) this makes sense: It states that certain dynamic visual properties deserve priority if they signal the need for immediate action, such as avoiding the potentially dangerous collision of an object with one's body. We investigated if the sense of behavioral urgency is hard-wired to our own body representation, or whether it flexibly transfers to an external representation of the observer, in this case an avatar in a 2D computer game. By controlling the avatar, the participant responded to shape changes of the target in a visual search task. Simultaneously, and completely irrelevant to the task, one of the objects on screen (possibly the target) could move. Target shape identification was speeded when the target was on a collision course with the avatar, rather than when it just passed it by, or moved away from it. Importantly, this prioritization of the target was only evident when it approached the player's avatar and not when it approached a character that was not under the observer's control. This suggests that the behavioral

urgency hypothesis not only holds for events possibly threatening to the observer's own body but also for external entities with which the observer can identify.

33.512 Effects of involuntary covert orienting and attentional control settings depend on the experimental task

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Four experiments investigated whether contingent attentional capture in the cue-target paradigm by Folk, Remington, and Johnston (1992) depends on the experimental task. In the cited study, participants' task was to discriminate which target (X or =) occurred inside one of four placeholders. The target was either the only appearing element (onset target) or the stimulus with a unique color among similar distractors (color target). A target was preceded by an onset or color cue appearing either at the same (valid cue) or a different (invalid cue) location as the subsequent target. It was found that cuing effects (faster responses for valid than for invalid cues) only occurred when both cue and target shared visual properties (i.e., both were onsets or both had a unique color). It was concluded that involuntary capture of attention is contingent on the target property participants are set to search for. Experiment 1 of the present study replicated Folk et al.'s (1992) experiment. Experiment 2 was equivalent except for the experimental task. Participants indicated where the target had appeared by a four-choice manual reaction. The localization task replicated contingent attentional capture, with larger effects than in the original task which suggests that motor priming also depends on attentional control settings. In Experiment 3, a detection task was used. Participants had to respond when they detected a target and to withhold the response otherwise. Notably, a high false alarm rate occurred when a color target was preceded by a color cue, suggesting that observers confuse cue and target displays. Experiment 4 measured perceptual accuracy using masked targets that were difficult to identify. Experiments 3 and 4 showed different interaction patterns than Experiments 1 and 2 in particular for onset targets, showing that contingent attentional capture depends on the type of experimental task.

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33.513 Attentional Set Produces an Inhibitory Surround in Color Space

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How is an attentional set for color instantiated? By one account a particular region of color space is enhanced focally, with this enhancement decreasing as the distance in color space from the focal region increases. Alternatively, feature inhibition may be applied to intermediate distances surrounding the enhanced region similar to inhibitory surround effects in orientation feature space (Tombu & Tsotsos, 2008). We tested these two alternatives using an attention capture task in the color domain. Method: Participants searched for a color outline circle target (e.g., red) among 3 gray non-target circles and reported whether a gap appeared at the top or bottom of the target. The target color was fixed across trials for each participant (determined from a set of L^*a^*b color coordinates centered at $a=10$, $b=10$, $r=50$). On each trial, a set of small, equally colored distractor dots briefly surrounded either the target or one of the distractor circles, prior to the target onset (Folk, Remington & Johnston, 1992). The distractor's distance in L^*a^*b color space from the target was parametrically varied between 0 and 180 degrees of polar angle, allowing us to quantify the extent of attention capture as a function of color distance. Results/Discussion: We found maximal interference by distractors sharing the same color as the target. Capture then decreased as the feature distance between the target and distractor increased. However, this decrease reached a minima at intermediate color distances (60 and 90 degrees), beyond which point interference increased. The pattern of interference was best categorized by a quadratic function. These results indicate that attentional set for color consists of both a central enhancement and an inhibitory surround, allowing efficient tuning to the behaviorally relevant feature.

33.514 Ignorance is bliss: The potential negative impact of knowledge on attention

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Perceptual load theory (Lavie, 1995) contends that distractor processing is dependent upon the availability of perceptual resources: distractor identities are processed under conditions of low perceptual load, but not under conditions of high perceptual load. However, recent evidence has shown that salient distractors – i.e., irrelevant color singletons – may sometimes be processed regardless of perceptual load, as indicated by distractor interference (Biggs & Gibson, 2010). But, whereas Biggs and Gibson observed that the salience of the distractor dominated load when the distractor appeared within the task-relevant search array, the present study examined whether the salience of the distractor would also dominate load under conditions in which the distractor was spatially separated from the task-relevant search display. Contrary to the findings reported by Biggs and Gibson, these findings suggested that the identity of the distractor was processed when perceptual load was low, but not when perceptual load was high. However, although the identity of the distractor did not appear to be processed in the high-load condition, the mere presence of a salient distractor nevertheless incurred a significant RT cost, suggesting a greater filtering cost for singleton distractors. Note that this cost was obtained even though observers had full knowledge of the color of both the search array and the distractor. Two subsequent experiments were conducted to investigate the nature of this filtering cost, one in which observers had only color knowledge of the search array and one in which they had only color knowledge of the distractor. Surprisingly, the results showed that the filtering cost arose only when observers had color knowledge of the distractor, suggesting that observers processed the distractor only when they had irrelevant knowledge about it. Thus, these findings are important because they show that some forms of knowledge can have detrimental effects on the control of attention.

33.515 Moment-to-Moment Fluctuations in Attentional Distraction by Motion: An fMRI Analysis

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While many researchers characterize attention as a mechanism dominated by either goal-driven (“top-down”) or stimulus-driven (“bottom-up”) processing, it is possible that attention routinely shifts along a continuum between these processes. Recent neuroimaging work has supported this possibility, showing moment-to-moment fluctuations in pretrial fMRI activity predict the magnitude of behavioral distraction by irrelevant color singletons (Leber, 2010, *J Neurosci*). Specifically, greater pretrial activity in middle frontal gyrus predicted diminished distraction. What remains unknown is whether and how fluctuations in attentional control regions like MFG interact with early perceptual processing of stimuli in visual cortex. In the current study, designed to address this question, we scanned participants who searched for a target square among nontarget circles. A motion singleton distractor (a nontarget) appeared on 50% of trials. Choosing a motion distractor allowed us to examine trial-by-trial variations in how the distractor was processed by motion-sensitive visual regions (MT/MST). Results showed that fluctuations were predicted in distraction to motion using pretrial fMRI activity in several regions. Specifically, greater pretrial activity in left precentral gyrus predicted greater resistance to distraction. In contrast, greater pretrial activity in left superior temporal sulcus and precuneus predicted greater susceptibility to distraction; this latter finding is consistent with the placement of these regions in the “default network,” which is anticorrelated with frontoparietal control regions. Analysis of trial-evoked activity in MT/MST failed to show modulations of distractor processing as a function of pretrial activity in regions that predicted distraction. Therefore, fluctuations in attentional control may not be evident in early stages of visual processing, although important limitations of this analysis will be discussed. In summary, distraction by motion varies on a momentary basis and is predictable using baseline fluctuations in fMRI activity from multiple distinct regions of cortex.

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33.516 Linguistic and Feature Cues Interact to Determine Saccadic Latency and Direction in Visual Search

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While much research has focused on the pull of attention to a location by irrelevant visual features outside the focus of attention (capture), research has only begun to investigate how these same features hold attention when they fall within the focus of attention. This is an important oversight as both the factors that influence the pull of attention to a location and the holding of attention at a location are crucial to understanding visual processing. Previous studies have found that completely irrelevant items within the focus of attention tend to hold attention when they share features of the target, and that subsequent shifts of attention are biased towards search items similar to the currently attended item (Boot & Brockmole, 2010; Brockmole & Boot, 2009). In this study, we examined whether these effects are limited to precisely matching visual features or if they are examples of a more domain and modality-general property of attentional allocation. Participants searched for a target defined by color (e.g., red) and initiated search by fixating an irrelevant item that could never be the target. This item was either red (matching the target), green (matching the distractor), or blue (neutral). Furthermore, immediately before the search display appeared, participants heard the word “red”, “green”, or “blue”. Both completely irrelevant linguistic and visual cues influenced search. When the item within the focus of attention matched the target, disengagement was delayed. When the item within the focus of attention matched the auditory cue, attentional disengagement was also delayed. Finally, eye movements were strongly biased to salient peripheral distractors when the linguistic cue matched the color of these distractors, similar to the effect of irrelevant visual cues seen in other experiments. Results have important implications for our understanding of how information from multiple modalities interact to influence attention and visual search.

Motion: Flow, depth, and spin

Sunday, May 8, 8:15 am - 12:15 pm

Vista Ballroom, Poster Boards 517 - 531

33.517 Modeling perceived depth from motion parallax with the motion/pursuit ratio

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The perception of depth from motion parallax may be described by a dynamic process that compares the proximal visual cues of retinal image motion ($d\theta$) and pursuit eye movements ($d\alpha$) to approximate the ratio of relative depth (d) to viewing distance (f) (Nawrot & Stroyan, 2009). This motion/pursuit ratio (M/PR), $d/f \sim d\theta/d\alpha$, represents a quantitative model for motion parallax and makes specific predictions of relative depth judgments (vis. $d \sim d\theta/d\alpha * f$). The goal of the current study is to determine how the M/PR characterizes perceived depth magnitude from motion parallax. In particular, the M/PR predicts foreshortening of depth from motion parallax, with magnitude of the foreshortening increasing with increasing M/PR . Observers performed comparisons of perceived depth magnitude between motion parallax and binocular stereopsis stimuli. A Z-Screen stereo system provided ocular separation for stereo stimuli and monocular viewing of parallax stimuli. Random-dot parallax stimuli translated laterally generating pursuit ($d\alpha$) while stimulus dots within the stimulus also shifted laterally ($d\theta$). The stereo stimuli, identical in composition to the parallax stimuli, were stationary. Parallax stimuli had a range of M/PR (0.04 - 0.24) while stereo stimuli had a range of disparities (1.2 - 11 min). For each M/PR , a point of subjective equality was estimated from the psychometric function, giving the amount of binocular disparity that generates the equivalent magnitude of perceived depth. Similar to previous results, perceived depth from motion parallax had significant foreshortening, even more than predicted by the M/PR . However, as predicted, foreshortening increased with larger values of M/PR . The M/PR provides a reasonable explanation for perceived depth from motion parallax. One explanation for

the additional depth foreshortening is the difference in pursuit signals generated by a translating observer fixating a stationary point, and a stationary observer pursuing a translating point.

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33.518 How noise affects complex motion perception

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Neurons in the MST area are sensitive to a continuum of combinations of rotational and translational motions. However, the receptive field structure of these neurons is still not well understood. Here, we investigated how local motions are integrated to compensate the noise in complex motions. We estimated the sensitivity to the rotational and to the radial components when the individual trajectories in a spiral pattern were randomly perturbed. Two conditions were tested - in the first each element had a fixed trajectory, while in the second the amount of trajectory perturbation varied on every frame. The width of the noise distribution added to the individual trajectories varied between 2° and 25°. We compared the discrimination thresholds for identifying the radial component in a spiral pattern as inward or outward and the rotational component as clockwise or counter-clockwise. The results indicate that when noise in successive frames is uncorrelated, the sensitivity to motion direction was higher than when each dot moves on a fixed trajectory. When the noise level was not too high, the discrimination thresholds were constant. Taken together, these results indicate that the integration of local motion in space and time reduces the effect of noise. However, the rotational discrimination thresholds exceeded significantly the thresholds for the radial motion and were less affected by the perturbation of the individual trajectories. This suggests that the integration of local motion is not uniform in all directions and/or that the local sensors are not independent. The reduced sensitivity to the rotational component of motion may be explained if motion sensors with opposite directional preferences integrate the flow information along circles centered at the preferred heading direction.

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33.519 Global speed perception in human vision is sensitive to the median physical speed of local image motions

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The human visual system is adept at encoding the global velocity of image motion by integrating local estimates of image speed and direction across space and over time. Yet the precise computations governing this integration process, particularly in the case of global speed perception, are still unclear. Psychophysical studies using random-dot-kinematograms (RDKs) have previously suggested that global speed discrimination is sensitive to the average, but not the mode, of the physical speeds present in the stimulus (Watamaniuk & Duchon, 1992; Vision Research 32: 931-941). However, perceived global speed was not directly measured and other statistical measures of central tendency (e.g. median and geometric mean) were not investigated. To address this issue, in the current study observers judged which of two RDKs had the faster global speed. In the standard RDK all dots moved with the same speed. In the comparison RDK each dot undertook a random-walk in speed drawn (with replacement) from an asymmetric distribution (either a skewed Gaussian or rectangular distribution) with distinct measures of central tendency. Results showed that, in general, perceived global speed tended to coincide with the median of the local physical speeds present in the stimulus and not the other statistics. However, under some conditions (when the comparison speeds were drawn from a rectangular distribution and were much slower than the standard) observers reported transparency and this adversely affected their ability to make reliable global speed judgements. When transparency was minimised by using RDKs with relatively high dot densities or brief durations, perceived global speed was still best characterised by the median physical dot speed. Consequently, global speed discrimination might only be sensitive to the average physical image speed when this inadvertently co-varies with the median speed.

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33.520 A Bistable Counterchange Detector for the Perception of Third-Order Motion

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Despite considerable evidence for attention-mediated changes in salience as the basis for third-order motion (Lu & Sperling, 1995, 2001), the nature of the motion mechanism responsible for its actual perception has not been established. A counterchange-sensitive, directionally selective motion detector has been proposed for this purpose. It entails the detection of oppositely signed changes in activation at pairs of spatial locations. A recently developed computational model based on the counterchange principle (Hock, Schöner & Gilroy, 2009) accounts for a wide range of phenomena for both generalized apparent motion stimuli (oppositely signed changes in contrast for two simultaneously visible surfaces) and standard apparent motion stimuli (when a surface is displaced its contrast disappears at its initial location and re-appears at its new location). An updated version of this model is presented which, in addition, accounts for the dynamical properties of apparent motion perception; i.e., it accounts for its bistability (both motion and nonmotion can be perceived for the same generalized apparent motion stimulus), the temporal persistence of these perceptual states, and the effects of adaptation. The feed forward path for the counterchange detector is composed of two biphasic subunits, one activated by decreases and the other by increases in activation input, with the motion detector's output determined by the multiplicative combination of the subunit activations (if both subunits are sufficiently excited, motion is perceived from the location of the decrease to the location of the increase in activation). Motion/non-motion bistability is established by activation-dependent feedback from the output of the motion detector to its biphasic subunits. The temporal persistence of these states for back-and-forth motion and the temporal integration of successive motions in the same direction are accounted for by activation-dependent interactions among different directionally selective motion detectors. The model makes several novel, experimentally-testable predictions that will further inform its plausibility.

33.521 Perception of bistable structure-from-motion stimulus, but not binocular rivalry, could be stabilized by visual context

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Perception of bistable stimuli could be stabilized when they are intermittently presented (Leopold, Wilke et al. 2002). However, when the stimuli are presented at different spatial locations, perception could be stabilized locally but switches between locations (Chen and He 2004). In this study, we examined whether contextual information, such as a bistable stimulus moving behind an occluder, would help stabilize the ambiguous perception across two spatial locations. Two different types of bistable stimuli were used, a bistable rotating cylinder (structure-from-motion) and dichoptically presented binocular rivalry stimuli. In the valid-context condition, the bistable stimuli slid into one side of an occluder and then emerged from the opposite side, creating the perception of an object moving back and forth behind the occluder. Subjects made perceptual judgment to the ambiguous pattern (direction of motion for the cylinder and the dominant pattern for binocular rivalry) when it appeared from each side of the occluder. In the invalid-context condition, the occluders were placed outside the two locations for the bistable stimulus so that the stimulus moved behind an occluder and then a new stimulus appeared at the second location without creating the impression that it was the same stimulus moving behind the occluder. Comparing to the invalid-context condition, valid context significantly stabilized the perceived rotating direction of the bistable cylinder across two locations; while the same contextual manipulation has no impact on perceptual switches of the binocular rivalry stimulus across two locations. These results suggest that the mechanism of perceptual stabilization of the structure-from-motion stimulus is more dependent on top-down factors while the stabilization of a binocular rivalry stimulus is much less sensitive to top-down contextual modulation.

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33.522 Isolation of binocular 3D motion cues in human visual cortex

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The binocular perception of 3-dimensional (3D) motion relies on both disparity-based and velocity-based cues, but relatively little is known about their physiological substrate. Surprisingly, psychophysical evidence has shown that direction discrimination for 3D motion is primarily supported by the velocity-based cue (Czuba et al., 2010). Previous work has implicated extrastriate areas in and around human MT+ (Rokers et al. 2009, Likova & Tyler 2007; respectively) as being involved in 3D motion processing. But it is unclear whether, where, and how the velocity-based and disparity-based cues are combined in the brain.

Here, we use a combination of psychophysical and event-related fMRI adaptation protocols to explore the neural processing of the two binocular cues to 3D motion. Identical random dot stimuli were viewed in a mirror stereoscope in both the psychophysics and fMRI. Observers adapted to 100 s of 3D motion directly towards or away from them. This 3D motion adaptation was followed by a series of 1 s probes, which moved in either the 'same' or 'opposite' direction as the adapter, and a subsequent 4 s top-up adaptation. In the imaging studies, attention was controlled using a demanding color-change detection task, and probe stimuli were occasionally omitted to isolate the probe response per se (Larsson et al., 2006).

We observed large psychophysical 3D adaptation effects that could not be accounted for by any reasonable inheritance of 2D effects. In good agreement, the fMRI clearly showed adaptation in (independently-defined) human MT+, but not in V1, implying a central role for MT+ in 3D motion processing. These results lay the groundwork for testing whether both the velocity-based and disparity-based cues are processed by a common mechanism selective for 3D motion direction.

33.523 Responses of human V6 to random motion, egomotion-incompatible and egomotion-compatible optic flow

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The extraction of optic flow cues from the visual scene is fundamental for guidance of egomotion. Area V6 is thought to be important in this role because of the properties of macaque V6 (Galletti et al, 1999), and because human V6 (hV6) responds differentially to egomotion-compatible optic flow compared to: (a) egomotion-incompatible flow (Cardin and Smith, 2010), and (b) incoherent motion (Pitzalis et al, 2010). It is not clear, however, whether hV6 responds more strongly to egomotion-incompatible global motion than to incoherent motion. This is relevant not only for determining the functional properties of hV6, but also in order to choose optimal stimuli for localising hV6 accurately with fMRI. Localization with retinotopic mapping is difficult and there is a need for a simple, reliable method. We conducted an event-related 3T fMRI experiment in which participants viewed a display of dots that moved randomly (RM), followed a time-varying optic flow trajectory in a single, egomotion-compatible (EC) display, or formed an egomotion-incompatible (EI) 3x3 array of optic flow patches as used in our previous work. Analysis was conducted by fitting a GLM. Beta values were extracted from retinotopically defined regions and averaged across hemispheres. Results from hV6 show an ordering of response magnitudes: EC>EI>RM. Neighbouring areas V3A and V7 responded more strongly to EC than to RM, but about equally to EC and EI. Our results suggest that hV6 may have a general role in the extraction of global motion but, in clear contrast to other neighbouring motion areas, is especially concerned with encoding EC stimuli. They suggest two strategies for localising hV6: (1) contrasting EC and EI; or (2) contrasting EC and RM, which will give a larger differential response, but requires use of standard retinotopic mapping in order to exclude voxels from neighbouring regions that also show a EC>RM preference.

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33.524 Cortical responses to time-varying optic flow patterns show differential tuning by pattern type, speed, and scalp location

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Adults show strong evoked electrical responses to direction-reversing optic flow fields organized in a radial (expansion/contraction) pattern, but weaker responses to rotation or lateral translation (Gilmore et al., 2007). Infants, in contrast, show the strongest evoked responses to lateral translation. Related research shows that adult and infant primates show different space/time tuning functions to global motion (Kiorpes & Movshon, 2004; Hou et al., 2009). In this study, we sought to determine whether adults show the same space/time tuning to different classes of flow patterns. We employed a high-density (128 electrode) montage to record steady-state visual evoked potential (SSVEP) responses to coherence modulations of three optic flow pattern types (left/right translation, rotation, and radial expansion/contraction) at three different speeds (2, 4, and 8 deg/s). Adult participants (n = 17; 11 female) viewed moving dot displays (7 amin dots, 79.4 cd/m², density = 10%) that modulated in time from incoherent to 100% coherent global motion at 1.2 Hz (1F1). The dot update rate remained constant for all displays (24 Hz, 1F2). Consistent with previous research, responses at the motion coherence modulation frequency (1.2 Hz, 1F1) were largest to radial motion patterns, with peak amplitudes observed over lateral occipital/temporal electrodes. SSVEP amplitudes to rotational and translational patterns were smaller in amplitude overall, with peak amplitudes shown along the occipital midline. The findings suggest that separable cortical networks may process time-varying radial, rotational, and translational optic flow patterns in human adults.

33.525 Does assessment of scene-relative object movement rely upon recovery of heading?

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We have provided compelling evidence that the recovery of scene-relative object movement is aided by neural flow parsing mechanisms which discount (subtract) global optic flow consistent with observer movement [Warren and Rushton, 2009, *Current Biology*, 19, 1555-1560]. Here, we examine whether flow parsing can occur independently from heading recovery. Stimuli comprised two simultaneously presented limited lifetime optic flow fields: 1. Expanding radial flow with focus of expansion (FOE) at the centre of the display; 2. Rightwards laminar flow. This stimulus gives rise to the optic flow illusion (OFI) under which illusory shifts in heading are perceived in the direction of laminar flow. Experiment 1: Observers viewed the OFI stimulus together with a probe moving upwards (~0.6°/s) from the centre of the display. After 2s stimulus presentation, observers reported the perceived probe motion direction by adjusting the orientation of a virtual paddle. If flow parsing depended on heading recovery under the OFI then perceived probe trajectory should tilt rightwards towards the illusory FOE. Instead, perceived motion was tilted leftwards. Experiment 2: To test that the results of experiment 1 were due to optic flow parsing we manipulated the configuration of the OFI stimulus (full field, left hemi-field only, right hemi-field only) and the start position of the probe (3 deg left/right of central fixation). When the probe was to the right, perceived trajectory tilted by 15-20° leftwards towards the centre. When the probe was to the left perceived trajectory was close to veridical. Crucially, the effects persisted when the probe was in the opposite hemi-field to the OFI stimulus – a key feature of global flow parsing. Again, these results are inconsistent with discounting of optic flow based on perceived heading under the OFI, suggesting that flow parsing does not necessarily depend on heading recovery.

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33.526 Heading recovery from optic flow: Comparing performance of humans and computational models

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Recovery of heading from optic flow (OF) has been studied extensively by experimental assessment of human performance and by building computational models capable of heading recovery. However, relatively little

work has made direct comparisons between models or between models and human performance. Here, we undertake such comparisons investigating heading recovery when OF density and dot direction noise are manipulated. Participants and a range of computational models viewed radial, limited lifetime dot OF fields and made 2AFC judgements about whether heading was to the left or right of a target in the scene. There were four possible horizontal target locations (± 2 , ± 4 deg from centre of display) and 10 possible horizontal focus of expansion offsets (± 0.2 , ± 0.5 , ± 1 , ± 2 , ± 4 deg relative to target). Dot motion orientation was corrupted by additive, zero mean Gaussian noise with standard deviation at one of three levels (0, 7.5, 15 deg). Dot density was varied by changing the number of dots in the field (5, 50, 100, 200). Thresholds for human observers dropped most sharply (by 50-75%) as number of dots increased from 5 to 50 but then performance stabilised. Furthermore, human observers showed some robustness to noise; when there were at least 50 dots in the display performance in the no noise and 7.5 deg noise conditions was similar but was degraded slightly in the 15 deg noise condition. Performance for the models tested varied greatly. Of these models, Longuet-Higgins & Prazdny (PRSL:Series B; 208(1173); 1980) model performed particularly poorly over the dot density range and showed little robustness to noise. In contrast, the Perrone (JOSAmA; 9(2); 1992) model was considerably more robust to noise and showed a qualitatively similar pattern of dependence on dot density to that seen in humans.

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33.527 A Model of MT Motion Pooling Explains Human Heading Bias

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In a rigid environment the observer's translational optic flow field has a focus of expansion (FoE) that specifies the direction of self-motion (heading) without eye rotations. Humans accurately judge to within 1 degree their direction of heading, unless the environment has independently moving objects (IMOs) that cross the observer's FoE. Studies have identified that IMOs that move horizontally with respect to the observer's translation and maintain a fixed distance bias human estimates of heading differently than those that approach the observer. While Royden & Hildreth (1996, Perception & Psychophysics 58) investigated non-approaching objects and found biases in the direction of object motion, Warren & Saunders (1995, Perception 24) found biases in the direction of the object's FoE for approaching objects. The motion-pooling model of W & S could not explain the findings of R & H. Royden (2002, Vision Research 42) argued that motion-opponent operators in primate area MT explained both sets of data, concluding that differential motion was critical to human heading estimation. This approach is difficult to reconcile with studies showing that motion pooling cells in MT project directly to dorsal MST, where direction-of-heading sensitive cells are located, but differential motion cells do not (Born & Bradley 2005, Annu. Rev. Neurosci. 28). We present a motion pooling model of MT and MST based on the model of Browning et al. (2009, Cog Psy 59) that demonstrates that differential motion is not necessary to explain human heading judgments. We generate motion sequences that mimic those viewed by W & S and H & R's subjects, using analytically computed V1 representations. Model MT pools over V1, followed by distance-weighted template-matching and competition stages in model MST. The model produces heading biases of the same direction and magnitude as humans ($r = 0.84$) while maintaining consistency with known primate neurophysiology.

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33.528 Ordinal depth from occlusion using optical flow: A neural model

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Problem. An occluding surface boundary is created by the spatio-temporal pattern of deletion and accretion of visual structure in which ordinal depth relations along the edge are defined by the arrangement of occluding and occluded surface regions (Gibson et al., Perception & Psychophysics 5, 1969). What are the neural computational mechanisms underlying the motion-based segregation of figure from ground based on occlusion boundary information?

Method. We propose a biologically inspired model of cortical motion detection and integration. Local motion signals are detected in model V1 which are spatially integrated over a larger neighborhood in model MT. Top-down feedback signals from MT to V1 disambiguate and stabilize the local measurements. The presence of temporal occlusions generated by surfaces hovering at different depths is evidenced by a transition from high motion energy when coherent motion is measured to low motion energy in cases of failure to find coherent spatio-temporal structure. In cases of temporal disocclusions low motion energy responses change into high motion energy response patterns. We propose an opponent scheme of temporal on/off interactions in which local motion energy signals from model V1 are spatially integrated by the temporally offset on/off subfields. This mechanism is gated by direction selective model MT cells to make the spatio-temporal occlusion detection selective to different motion directions.

Results. The model was probed with artificial scenes of moving and mutually occluding object surfaces. Motion is estimated by the model and activities at the stage of occlusion detection correctly indicate the foreground objects when they partially occlude the background. The occlusion/dis-occlusion boundary responses together with directional motion signals determine the border-ownership direction of an occluding surface. This demonstrates that spatio-temporal figure-ground separation can be achieved by local mechanisms at early and intermediate stages of the dorsal visual pathway.

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33.529 Near-optimal spatial integration of optic flow information for direction of heading judgments

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Purpose: We tested whether human observers maintain ideal patterns of information use across the visual field (VF) in determining direction of heading (DOH) from optic flow. Methods: Six participants aged 18-22 fixated centrally while monocularly viewing flow patterns simulating straight-line movement in depth through a 3D cloud of dots. DOH on base trials (20% of all trials) was set at 3°, 6°, or 9° eccentricity along the 4 diagonal axes of the VF. On perturbed trials (half of all trials), three VF quadrants indicated 6° DOH along one axis and one quadrant indicated 3° or 9° DOH along the same axis (a 3° perturbation). On 30% of trials, the DOH was chosen randomly from a circle with 10° radius. Stimulus information within 10° of fixation and outside 20° eccentricity was occluded. Subjects indicated their perceived DOH with an optical pointer. Multiple linear regressions were performed on DOH responses to determine relative weights given to each quadrant. Quadrants were labeled spatially, e.g. upper-right and lower-left, and functionally, e.g. DOH-containing quadrant, adjacent quadrants and opposite quadrant. Results: Subjects gave greatest and lowest weight to the quadrants containing the most and least useful information respectively, as predicted by the Crowell & Banks (1996) ideal observer model. Quadrants adjacent to that containing the DOH also differed in horizontal and vertical influence on perceived DOH. However, while an ideal observer would weight each spatial quadrant equally across the information-balanced conditions, human observers deviated from this pattern, giving more weight to quadrants above the horizontal midline. Conclusions: While the ideal observer model explains some of the complex patterns human observers exhibit in weighing information across the visual field, it did not predict their bias to rely on the upper half of the visual field in determining direction of heading from optic flow.

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33.530 Color and luminance for motion-in-depth

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[Purpose] Motion in depth can be perceived based on interocular velocity differences (IOVDs) caused by monocular motion aftereffect (MAE). In order to investigate how the IOVD integrates signals from the luminance

and color motion channels, we conducted experiments to reveal whether this integration is implemented before or after the comparison of the velocity signals from the two eyes. [Experiment] We measured cross adaptation effects between luminance and color motion signals in MAE of motion in depth (3D MAE). Adaptation stimulus was either luminance or red/green gratings drifting laterally in Exp. 1 and we also used yellow/blue gratings in Exp. 2. After adapting either the left or right eye to the drifting grating, the duration of 3D-MAE was measured with the static version of the color or the luminance grating. To confirm color motion system is concerned in color motion conditions, we varied temporal frequency (with a fixed spatial frequency), expecting different temporal frequency characteristics between the luminance and color motion systems. [Results] After the color adaptation, MAE duration showed longer with lower temporal frequencies (low-pass) while it showed the longest around 5 Hz after the luminance adaptation (bandpass) for both 2D- and 3D-MAEs with longer absolute duration for 2D-MAE. This trend was the same for the luminance and color tests both in Exps. 1 and 2. These results indicate 1) that color motion signals are used to see motion in depth through the IOVD and 2) that integration of color and luminance motion signals occurs at a stage of 2D motion and the IOVD is calculated from the combined motion signals. The present results also suggest that there is an energy based color motion system since it is highly unlikely to calculate IOVDs through a high level mechanism such as feature tracking.

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33.531 Motion induction or assimilation in depth in a frontoparallel moving display? The importance of depth cues

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Induced motion in the frontoparallel plane occurs when viewing displays composed of a vertically oscillating target dot enclosed within a horizontally oscillating inducer frame. In such displays, the dot appears to be moving diagonally, as would be predicted from subtracting the frame's motion from that of the dot. Separating the frame and the dot in depth has only a limited influence on induced motion, suggesting that the 3D layout of the visual scene does not affect frontoparallel induced motion. On the other hand, previous experiments have demonstrated the possibility of induced motion in depth when the dot and frame move along that dimension. Here, we demonstrate in two experiments that a component of motion in depth emerges in a frontoparallel moving display but where a degree of slant is imparted to the inducer frame, using either monocularly or binocularly viewed perspective, or disparity as depth cue. Our results show that the target dot is perceived as moving in depth either along the surface of the frame (3D motion assimilation) or against it (3D induced motion) when the dominant depth cue is perspective or disparity, respectively. We propose a model of motion perception which predicts this pattern of results based on the hypothesis that relative depth is computed only locally, consistent with an earlier model formulated for the case of static displays.

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3D perception: Dynamic cues

Sunday, May 8, 8:15 am - 12:15 pm

Vista Ballroom, Poster Boards 532 - 538

33.532 Perspective transformations and depth scaling in stereopsis and motion parallax

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Background: In binocular stereopsis, the differential-perspective transformation between the two eyes (vertical disparities) provides an estimate of the included (vergence) angle that can be used to scale horizontal disparities (Rogers and Bradshaw, 1993, *Nature*, 361). In observer-produced motion parallax, the vertical-perspective transformation over time (Braunstein, 1977, *Perception & Psychophysics*, 21) provides an estimate of the observer's angle of rotation with respect to the scene that could also be used to scale perceived depth. Both transformations represent 'whole field' properties that could be integrated over the entire visual field. Purpose:

The present experiment was designed to measure and compare the spatial integrative properties in the two domains. Methods: Large field displays (55°x55°) were used to present horizontally-oriented sinusoidal corrugations in depth either binocularly (disparity information) or monocularly, (observer-produced parallax information), within a textured surround that could be masked down to 35°x35°; 20°x20°; or 10°x10°. Force-choice thresholds for discriminating a difference in perceived depth were obtained firstly (in the conventional way) by varying the amount of disparity/parallax motion and secondly by varying the amount of differential perspective information (mimicking a different included angle) or vertical perspective information (mimicking a different angle of rotation). Results: Conventional Weber fractions for discriminating disparity- and parallax-defined surfaces were between 7-9% and 8-11%, respectively for different observers. The slopes of the psychometric functions obtained when the amount of differential- or vertical-perspective was manipulated decreased with a decrease in the overall size of the display, in both domains. Differential-perspective manipulations did not affect perceived depth when the display size was smaller than 10°x10° while vertical-perspective manipulations were effective in parallax displays down to 5°x5°. Conclusions: There is a similar pattern of spatial integration for differential- and vertical-perspective information that extends over a large portion of the visual field but the minimum critical area is significantly smaller in the parallax case.

33.533 Perception of slant by an active observer remains constant when looking at a rotating but not at a static plane

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The relative rotation between a static planar surface, slanted around the vertical axis, and a laterally translating observer produces a continuous variation of the instantaneous gradient of the optic-flow (def). According to Wexler, Lamouret and Droulez (2001), non-visual information about head movements is used together with the stationarity assumption (i.e., 3D objects are static in an earth-fixed reference frame) to compensate for the optic-flow variation in order to achieve an allocentric representation of the surface which is not changing orientation during the execution of the head movement. An alternative theory postulates that non-visual information is ignored, and that only the instantaneous optic-flow determines perceived 3D-structure (Fantoni, Caudek and Domini, 2010); accordingly, a static plane should be perceived as changing its orientation during head movement. Here, we contrasted these two theories by studying perceived slant for planes with 0° tilt viewed during lateral head movements. Two types of random-dot planes were used: static, with varying def, and rotating, with constant def. Constant def during head movements was achieved by appropriately coupling the surface rotation with the head translation. In this condition, perceived slant is expected to vary for the first theory, but not for the second (given that def was constant). Results were consistent with the second theory. Perceived slant was dramatically affected by the instantaneous def variation when monocularly viewing the static, but not the rotating planes. Perceived slant of the static planes was 35% larger when the def at the end of the head movement was large relative to when it was small. No such an effect was found for rotating planes although their allocentric orientation varied during head movements. Our finding is inconsistent with the stationarity assumption. Active perception of plane orientation depends on the instantaneous def at the end of head motion, not on the average def.

33.534 Human stability perception implies sophisticated knowledge of physical dynamics

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People can perceive and predict physical properties of objects, even in complex and unfamiliar situations; for instance, judging whether a stack of several objects is stable or unstable is usually not difficult. These judgments suggest the brain has an internal understanding of physics concepts such as gravity, friction, and inertia. Some have argued that humans' "intuitive physics" is biased and poor when interpreting inertial dynamics, but the breadth and sophistication of humans' general visual physical reasoning is at odds with these accounts. Our work measures the boundaries of humans' stability perception to uncover the underlying cognitive mechanics that facilitate these behaviors.

We conducted a set of human psychophysical experiments in which participants viewed virtual 3D scenes of different configurations ("towers") of ten blocks. Participants judged whether each tower was stable or not, which direction/how far it would fall if it was unstable, and what external force magnitude would be required to cause it to collapse if it was stable. We compared participants' judgments to a model "physics perception" observer that made these judgments by simulating true physical dynamics with minor positional noise added to the tower's individual block locations, and found people and model were highly consistent. We tested for learning by providing visual feedback of whether the tower collapsed to one group of participants, and no feedback to another, but found no significant differences between the groups. Several possible heuristics exist for performing this task (e.g. tower height proportional to instability), but we ruled them out because they underperformed the model predictions, and because participants made model-consistent judgments in a same-height tower control task. These results suggest humans apply concepts like gravity, solidity, and support in an approximate dynamics simulation to make physics judgments, rather than relying on weak, biased, special-case heuristics.

33.535 Classifying Dynamic 3-D Shape Deformations from Motion Cues

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Many organisms and objects deform when moving, requiring perceivers to separate shape changes from object motion. We have shown that 3-D shape extraction from motion cues is as good for non-rigid as for rigid objects. Here we address observer abilities to identify different classes of dynamic shape deformations. Point-light cylinders that were either rigid (with assorted axial curvatures) or flexing in depth or in the image plane, were rotated simultaneously in depth and the image plane, and presented monocularly in perspective projection. Texture and density cues were removed by placing point-lights randomly on the 3-D surface after rendering. Using a method of constant stimuli, the amount of flex was varied across trials, and observers had to classify each cylinder as rigid, flexing in depth, or flexing in the image plane. Due to the complex rotation and the curved shapes, the projected contours of cylinders of all three classes varied in curvature during the trial, so contour deformation was not informative for identifying the class. Results were consistent across three observers. Depth-flex cylinders were perceived as rigid for low values of non-rigidity and as depth-flex for higher values. Plane-flex cylinders were confused with depth-flex cylinders for low non-rigidities and were perceived veridically for high values. Rigid cylinders bent in depth were slightly confused with depth-flex cylinders, but rigid cylinders bent in the plane were seen as rigid. There are no published models that identify shape deformations from motion cues. Eigen-shapes extracted from image sequences can distinguish between rigid and flexing cylinders, but not the viewer-centered distinction between depth-versus plane-flex. We combine relative image velocities into the differential invariants div, curl, and def. We show that the gradient of def is zero for rigid but non-zero for flexing cylinders, and explore combinations with curl and div that could classify dynamic deformations.

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33.536 Segmentation and depth from motion parallax-induced dynamic occlusion

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A powerful cue to the 3D layout of the world is differential image motion resulting from observer movement (motion parallax). Previously (VSS 2010) we measured its role in segmentation and depth perception from shear motion. Here we extend these experiments to the equally important case of dynamic occlusion, which contains both compression-expansion and accretion-deletion cues. Observers performed lateral head translation while an electromagnetic tracker recorded head position. Stimuli consisted of random dots whose horizontal displacements were synchronized proportionately to head movement by a scale factor ("syncing gain") proportional to depth, and were modulated using periodic velocity envelopes to generate dynamic occlusion motion. Segmentation performance was assessed by measuring discrimination thresholds for envelope orientation. This task included two conditions: one in which stimuli were synched to the head motion, and the other in which previously recorded stimulus motions were "played-back". In the depth-ordering task, subjects reported whether the half-cycle left or right of the centre of the screen appeared

nearer. We compared conditions in which accretion-deletion occurred in an ecologically correct or incorrect relationship, or was absent. Depth-ordering showed robust performance across a wider range of syncing gains compared to shear. In the cue conflict condition, reported depth was consistent with motion parallax at low syncing gains, but consistent with accretion at high syncing gains; segmentation showed similar results for head motion and playback, for correct and incorrect accretion-deletion, and similar or slightly better performance compared to the results from shear. These results demonstrate that dynamic occlusion is a more powerful cue than shear in extracting depth and segmentation information from motion parallax. The results also suggest that motion parallax more effectively signals small depth differences within an object, whereas accretion-deletion provides more information about larger depth differences between separate objects or an object and a background.

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33.537 The peak motion/pursuit ratio and structure from motion parallax

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The perception of relative depth from motion parallax relies on an internal pursuit signal generated to maintain stable fixation during observer translation (Nawrot & Joyce, 2007; Nadler, Nawrot, Angelaki, DeAngelis 2009). In (Nawrot & Stroyan 2009) we mathematically derived a formula for relative depth from motion parallax using the ratio of the rate of retinal motion over the rate of smooth pursuit eye movement, the motion/pursuit ratio. The mathematics describes a laterally translating observer who fixates on one point and judges the depth of another point in central vision. We also confirmed, psychophysically, that judgments of relative depth agree with this dynamic geometric model. For points in central vision, the motion/pursuit ratio determines relative depth instantaneously, mathematically, and in less than 100 msec for people (Nawrot & Stroyan, 2010), but a single instantaneous observation does not give an accurate representation of the depth of points outside central vision. As an observer moves, the motion/pursuit ratio at a point changes and reaches a peak value at a time depending on that point. Mathematical recovery of the structure of objects that extend beyond central vision is possible using a longer duration integration of the motion/pursuit ratio over the points on the object. We present an analysis and computer simulation of how the motion/pursuit ratio gives accurate structure from motion parallax using the peak values of the motion/pursuit ratio.

While it is empirically known that the relative depth of points on an object may be perceived quickly and accurately in central vision, our mathematics suggests that the perception of the structure of an object that extends beyond central vision might be accurately perceived by longer duration integration of only the motion/pursuit ratio.

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33.538 A computational explanation of the stereokinetic effect

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Purpose: We aimed to explain (1) why a three-dimensional (3D) object is perceived when a 2D shape is rotated in the image plane; and (2) why, once the 3D object is perceived, it is nearly impossible to flip back to the 2D percept. We tested two competing hypotheses: (1) A motion interpretation is preferred if it gives rise to a slower and spatially smoother optic flow (Yuille and Grzywacy, 1988; Weiss, Simoncelli, and Adelson, 2002). (2) An object in 3D with better gestalt is preferred (e.g., a circle versus an ellipse). Method: We used a rotating ellipse as an example since it had been studied with in 2D (Weiss et al., 2002) and in 3D (Rokers, Yuille, and Liu, 2006), which were never compared, however. We first replicated Weiss (1998) and confirmed that a motion interpretation of a deforming ellipse has a lower optic flow than a rigidly rotating ellipse. We then computed the 2D motion flow under the interpretation of a wobbling disk, and found that the optic flow was even smaller than that of a deforming ellipse. Finally, we verified Yuille's proof (2006) that the slowest flow results from 2D, rather than 3D, motion, when there is no smoothness constraint. The resultant motion flow is not spatially smooth, and is never perceived. Hence, the necessity of smoothness constraint in motion perception is supported. Conclusions: Our results suggest that the perceptual transition from a deforming ellipse

to a wobbling disk can be explained by the slow and smooth constraints alone. The third dimension in depth and rigidity are unneeded. Nor is the better gestalt of a circle than an ellipse, since this leaves unexplained the specific perceived motion. A better alternative interpretation is that a circle maximizes the options of correspondence, enabling slower and smoother motion to be perceived.

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Temporal processing

Sunday, May 8, 8:15 am - 12:15 pm

Vista Ballroom, Poster Boards 539 - 557

33.539 The Many Directions of Time

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Recent research has uncovered independent subsecond visual timing mechanisms, each monitoring a distinct region of visual space. We reveal that, rather than a one-to-one mapping of spatial location and timing mechanism, each region of visual space is assigned multiple, direction-contingent neural timing mechanisms. In Experiment 1, observers adapted to a peripheral, translating random dot kinematogram. Following adaptation, perceived duration was measured for a 600ms test pattern in the same retinal location as the adaptor. The test pattern moved in either the same or opposite direction as the adaptor. Duration compression of the test pattern was observed in the former, but not the latter, condition; suggesting that multiple, neural timing mechanisms monitor each region of visual space. Furthermore, their direction-contingent nature points to these mechanisms being cortical in origin. Experiment 2 investigated whether these timing mechanisms occur at the global motion processing level. Following adaptation to a translating plaid pattern, which is known to selectively activate neurons in cortical area MT+, observers judged the duration of a random dot pattern moving in the same location and direction as the plaid. The resulting duration compression provides compelling evidence that the underlying neural timing mechanisms occur at the global motion processing level. Our results are consistent with a recent model of time perception (Periyadath & Eagleman, 2007), in which subjective duration of a stimulus is influenced by the amount of neural activity involved in representing the stimulus. Viewed from this perspective, the observed duration compression of test stimuli moving in the same direction as the adapting stimulus is driven by the reduced responsiveness of motion-sensitive neurons tuned to the adapting direction. The lack of duration compression for stimuli moving in the opposite direction is consistent with neurons sensitive to this direction maintaining their responsiveness in the face of the adaptation process.

33.540 Life motion signals lengthen perceived temporal duration

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Point-light biological motion stimuli have particular spatiotemporal properties that enable them to be processed with remarkable efficiency. Human observers can readily recognize action, gender, emotion, and identity information conveyed by dynamic point-light walkers. All these processes require temporal integration, yet little is known about the encoding of biological motion temporal information. Here we report a novel temporal illusion: biological motion signals significantly lengthen perceived temporal duration in a manner that is independent of conscious awareness of biological nature. In a parametric time discrimination paradigm, we showed that the same presentation duration of an upright biological motion sequence was perceived significantly longer compared with that of an inverted motion sequence. This overestimation effect was not due to the familiarity of the global configuration, since an upright static biological motion frame showed no difference when compared with an inverted one. Moreover, such temporal illusion persisted with spatially scrambled biological motion signals, whose global configurations were completely disrupted, independent of the observers' explicit knowledge of the nature of the stimuli. These findings provide strong evidence that biological motion has particular temporal properties that distinguish itself from other forms of motion and highlight the intrinsic sensitivity of the human visual system to local biological motion signals.

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33.541 The Effect of Simultaneous Context on Perceived Duration

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Adapting to high temporal frequency oscillating gratings or flickering Gaussians reduces the apparent duration of a subsequently presented sub-second dynamic stimulus (Johnston, Arnold & Nishida, 2006, *Current Biology*, 16(5):472-9). Here, we measured adaptation-induced temporal distortion using counterphase-modulated gratings and then investigated whether the perceived duration of a counterphase flickering central grating is influenced by a simultaneously presented surround, which would indicate contextual effects in duration perception. In the first experiment, the standard (10Hz, 600ms, 1c/deg) was presented at the adapted location while the comparison (100-1100ms) was always displayed on the unadapted side. The apparent temporal frequencies of the two tests were matched using individual measurements of the temporal frequency shifts that could be observed following adaptation. Adaptation to 20Hz induced duration compression with adaptation to 5Hz inducing weaker duration compression. Overall duration compression was weaker for counterphase-modulated adaptors as compared to drifting or Gaussian flickering adaptors. In the second experiment, a standard disc (10Hz, 600ms) was surrounded by a 5 or 20Hz counterphase-modulated annulus (2sec) in two different blocked conditions. The comparison stimulus (100-1100ms, 10Hz) was always surrounded by a 1Hz counterphase-modulated annulus (2sec). The onset and offset of the tests relative to those of the surrounds were randomised across trials. Using a similar procedure to Experiment 1, the apparent temporal frequency of the standard was matched to that of the comparison. The task was to compare the duration of two sequentially displayed tests both temporally embedded in and surrounded by a dynamic surround. We found that while a 20Hz context induced a ~12% statistically significant expansion ($p=0.012$) of the perceived duration of the central pattern, no statistically significant difference was observed when the surrounding context was 5Hz. The modulation of the duration of the inner disc by non-overlapping surround provides evidence for long-range spatial interactions in duration perception.

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33.542 Apparent duration expansion at low luminance levels.

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It has been suggested that visual adaptation-based duration compression (Johnston, Arnold & Nishida, 2006, *Current Biology*, 16(5):472-9; Bruno & Johnston, 2010, *Frontiers in Psychology*, 1(170): 1-8) might be related to the shortening of the temporal impulse response in M neurons (Kaplan & Benardete, 2001, *Progress in Brain Research*, 134:17-34). The temporal impulse response lengthens (by around 30%) and neural latencies increase at low light levels (Kelly, 1961, *Journal of the Optical Society of America*, 51:422-9; Peterson, Ohzawa & Freeman, 2001, *Visual Neuroscience*, 18: 203-8) suggesting visual duration may appear to expand in the dark. We first measured a progressive shift and reduction of the occurrence of an apparent motion reversal as we decreased the luminance level, indicating a lengthening of the temporal impulse response (Takeuchi & DeValois, 2009, *Vision Research*, 49(8):801-9). We then measured perceived duration at these luminance levels (0.75, 3 & 50 cd/m²) after 25 minutes of dark adaptation. We asked subjects to compare the relative duration of a flickering Gaussian blob with that of an amplitude-modulated (AM) tone after equating the apparent contrast and the apparent temporal frequency of the visual flicker at the different light levels (relative to an AM tone with variable frequency). While the temporal frequency estimates did not substantially differ across luminance levels (the visual stimulus appeared to flicker at a higher rate than the AM tone), duration seemed to be expanded at the lowest luminance level (0.75 cd/m²) relative to the highest (50 cd/m²) by approximately 60 ms. Thus we have shown reduced luminance is associated with both a lengthening of the temporal impulse response and a dura-

tion expansion, linking the two, and providing further evidence for a relationship between changes in the tuning of the neurons in the early stages of the magnocellular pathway and time perception.

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33.543 Spatial topography of saccade induced chronostasis

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Saccade induced chronostasis ("The stopped clock illusion") is defined as the subjective lengthening of the duration of a stimulus. Chronostasis has typically been described at the saccade endpoint. We recently showed that chronostasis can also be found at the starting point of a saccade (Knöll & Bremmer, VSS 2009). This led us to suggest that chronostasis occurs globally, but may differ in its strength and time course across space. In our current experiment, we hence measured the spatial topography of saccade-induced chronostasis. To this end, we measured temporal perception for stimuli shown perisaccadically either at the start, midpoint or end of the saccade trajectory. Human observers performed a saccade task with stimuli displayed on a CRT screen at 57 cm distance. Eye movements were recorded at 500Hz with an infrared eye tracker (Eye-Link 2, SR-Research). A white square (40cdm⁻²) was shown constantly for the duration of each trial on a gray background (20cdm⁻²) at either of three positions: -10° (initial fixation), 0° (saccadic midway) or 10° (saccade target). 500 to 1000ms after trial onset, subjects were cued to perform a saccade. At ±200ms around the expected onset of the saccade the white stimulus turned dark (10cdm⁻²) either for a variable duration or 500ms. After an ISI of 750ms an otherwise identical comparison stimulus was shown for 500ms or a variable duration, respectively. Points of subjective equality were obtained at all three locations by asking subjects to indicate whether the first stimulus lasted longer than the second. We confirm previous findings of chronostasis at the start and end of the saccade. In addition, we find clear evidence of chronostasis at the midpoint of the saccade trajectory. Hence, chronostasis like other perisaccadic perceptual phenomena (saccadic suppression, spatial perception) occurs globally. The neural basis of this perceptual effect remains to be determined.

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33.544 The influence of retinal and head-centered motion on perceived duration

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The apparent duration of moving stimuli increases with temporal frequency (Kanai et al., Journal of Vision, 2006) or speed (Kaneko & Murakami, Journal of Vision, 2009). Here we investigated if this increase depends on retinal or head-centered temporal frequency respective speed. Smooth pursuit eye movements were used to disentangle retinal from head-centered motion.

We presented two Gabors in separate time intervals and asked subjects to judge which one lasted longer. The Gabors had a sinusoid spatial frequency of 1 c/deg, a Gaussian standard deviation of 0.75 deg and were presented 4 deg above or below a fixation point. One Gabor had a fixed duration of 500 ms (standard) and was oriented vertically, so that its retinal speed was modulated by horizontal eye movements. The other Gabor had a variable duration (test) and was oriented horizontally, so that its retinal speed was independent of horizontal eye movements. The order of standard and test was randomized. In a fixation baseline condition the fixation point was stationary and the standard Gabor was drifting inside the stationary envelope at speeds of 3.5, 7.0, 10.5 and 14.0 deg/s. In two different pursuit conditions the fixation point moved horizontally at the same speeds: In a retinal motion condition, the standard sinusoid was physically stationary but moving on the retina. In a head-centered motion condition the standard sinusoid drifted at the same speed as the fixation point, so that it was stabilized on the retina.

The apparent duration increased with speed in the fixation baseline condition. In the retinal motion condition, the increase of apparent duration was similar to the fixation baseline condition. However there was almost no increase of apparent duration with speed in the head-centered motion condition. These results suggest that perceived duration depends on retinal rather than on head-centered motion.

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33.545 Glance, Glimpse or Stare? The discrimination of gaze duration

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While a considerable amount of work has focused on the perception of gaze direction, there has been little consideration of gaze duration. This is surprising insofar as social cues mediated by gaze are contingent on interactions between perceived gaze direction and duration. Participants were presented with two computer-generated faces one on either side of fixation. In the mutual gaze condition, participants were asked to judge which was the longer of two intervals defined by a shift in gaze from one side of the participant's head to mutual gaze and back. In the averted gaze condition, intervals were defined by a switch in gaze from one side of the participant's head to the opposite side and back. The standard gaze duration presented on one side of fixation lasted 625ms. The comparison interval presented on the other side ranged from 100 to 1600ms to define a psychometric function. The order of presentation was randomised over trials. The discrimination threshold was defined as the slope of the psychometric function. For upright faces we found that participants' discrimination of mutual gaze duration was better than discrimination of intervals of averted gaze. In contrast, there was no difference between mutual and averted discrimination for inverted faces. In a second experiment, using similar methods, we show that participants' discrimination of eye-colour did not vary as a function of gaze direction, when changes in iris colour coincided with changes in gaze. This argues against selective enhancement of upright mutual gaze duration discrimination mediated by greater attentional capture or elevated arousal, as these accounts predict improved discrimination across a range of psychophysical tasks. We propose that the detection of upright mutual gaze recruits a gated domain specific timing mechanism, with a high temporal resolution, allowing the precise representation necessary to interpret the social cues afforded by mutual gaze.

33.546 The time-dilation aftereffect depends on orientation and eye of origin

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Several seconds of adaptation to a flickered (5 Hz) stimulus makes a subsequently presented brief static stimulus appear longer in duration. What causes this time-dilation aftereffect? We investigated this question using a standard temporal-bisection task, where observers classify (in a 2AFC manner) whether the test stimulus, varying between 200 and 800 ms, is closer to the short or long reference duration remembered prior to experimental trials. A shorter PSE (i.e., a shorter physical duration perceived to be the bisection point of 500 ms) indicates a larger amount of perceptual time dilation. Using this technique, we previously showed that the flicker adaptation time-dilation aftereffect is significantly reduced by a 90° change in Gabor orientation between adaptation and test. However, high-level as well as low-level visual neurons are sensitive to a 90° orientation change, and observers were conscious of the orientation change. Our previous results thus are consistent with contributions from high-level visual processing and/or cognitive processing as well as with low-level processing. Our current experiments demonstrate that the time-dilation aftereffect is also significantly reduced by a much smaller 45° orientation change, suggesting the involvement of lower-level visual neurons (orientation-tuning bandwidths are approximately 25–40° in V1, 35–75° in V4, and 70° in IT). Furthermore, the time-dilation aftereffect is significantly reduced when the adaptor and test stimuli are presented to different eyes than when they are presented to the same eye. Because eye preferences are strong in V1 but diminish in high-level visual areas, the specificity for eye of origin corroborates the involvement of low-level visual neurons. Further, because people are generally unaware of the eye-of-origin information, cognitive processing is unlikely to have mediated this specificity. Taken together, our results suggest that flicker adaptation of low-level visual neurons contributes to expanding the perceived duration of a subsequently presented static stimulus.

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33.547 **Flicks and ticks: microsaccade-related compression of perceived duration.**

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Human perception of time is prone to errors. One remarkable example is the compression of perceived duration at the time of saccades (Morrone, Ross, & Burr, 2005) or smooth pursuit eye movements (Schütz & Morrone, 2010). We were interested whether similar misperceptions occur during other types of eye movements, which stabilize fixation. Investigating the perception of duration at the time of microsaccades might contribute to the understanding of the saccade-related compression of time, given that the neural machinery responsible for both movements is partly shared but their perceptual effects, such as visual suppression, do not necessarily overlap. To this aim, we had observers reproduce the duration of peripheral high-frequency (2.5 cyc/deg) vertically oriented Gabor patches. We chose this display as we expected it to bring about strong visual transients at the occurrence of microsaccades, which are mainly horizontally oriented and have horizontal amplitudes in the range of our stimulus wavelength. The gratings were presented for 259 to 706 ms and participants re-produced their duration with a keypress when prompted by a go-signal which appeared 700 to 1700 ms after the offset of the grating. Our observers consistently reproduced the duration as shorter when they had executed a microsaccade while the grating was present, as compared to the trials where no microsaccade was detected. This effect was evident in particular for durations above 500 ms and its magnitude, about 30 ms, was comparable to the average duration of microsaccades. Overall, our data indicate that the duration of visual events at the time of microsaccades is compressed, despite the fact that microsaccades are involuntary and are not associated with a suppression of visual signals. This finding parallels the results of experiments on saccades and smooth pursuit eye movements and questions the hypothesis that saccade-related time compression is due to reduced stimulus visibility.

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33.548 **Tempo rubato**: animacy speeds up time in the brain

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Timing visual events over the scale of tens to hundreds of milliseconds is essential for successful interactions with the everyday surrounding environment. The idea that events are timed by a centralized clock has recently been called into question in favour of distributed, specialized mechanisms. Here we provide evidence for a critical specialization: animate and inanimate events are separately timed by humans. In different experiments and without performance feedback, observers were asked to intercept a moving target or to discriminate the duration of a stationary flash while viewing different computer graphics scenes. In the scene background one of six moving characters was displayed. The most natural character type was denoted as Biological-Motion because it was endowed with the kinematics recorded from a real human actor. Naturalness and animacy were degraded in the Upside-Down character where the human figure was displayed in a vertically inverted orientation and in the character type Time-Shifted whose motion was obtained from the original by randomly time-shifting the angular motion of single segments. These animate characters were contrasted with inanimate characters (Rigid-Translation, Double-Pendulum and Whirligig) whose appearance was clearly artificial. However, the fundamental motion harmonic content of the inanimate characters was matched to that of the original unperturbed animate motion. Subjects rushed to intercept a falling ball in an animate context, whereas they dragged when the context was inanimate. Also, subjects estimated the duration of a stationary flash as being shorter in an animate than in an inanimate context. Remarkably, the animate/inanimate context also affected randomly intermingled trials which always depicted the same still character. The existence of distinct time bases for animate and inanimate events might be related to the partial segregation of the neural networks processing these two categories of objects, and could enhance our ability to predict critically timed actions.

33.549 **Optimal coding of interval timing in expert drummers, string musicians and non-musical control subjects**

Guido Marco Cicchini¹(cicchini@in.cnr.it), Roberto Arrighi², Luca Cecchetti², Marco Giusti², David Burr^{1,2}; ¹Institute of Neuroscience, National Research Council (CNR) - Pisa, Italy, ²Department of Psychology, University of Florence, Florence, Italy

Jazayeri and Shadlen (Nat. Neurosc. 2010) recently reported that when human observers reproduce time intervals drawn from different distributions production times exhibit a systematic regression towards the mean. They explained and model their data with a performance-optimizing Bayesian model. We repeated their study on a population of expert drummers, string musicians and non-musical control subjects, with both visual and auditory stimuli. For auditory stimuli, no subjects showed regression towards the mean. For visual stimuli, the non-musical control subjects showed a strong regression, but the drummers maintained near-veridical performance with almost no regression to the mean. The string musicians showed intermediate behaviour. We measured separately temporal precision for auditory and visual stimuli with a bisection task. Auditory precision was higher than visual precision, and the drummers were more precise in both domains. Interestingly, there was a strong negative correlation between precision in the bisection task and regression towards the mean in the production (more precise subjects regressed less). We model these data with a modified performance-optimizing Bayesian model, where the prior is calculated from a running mean of previous trials.

Acknowledgement: EU, FP7 - STANIB

33.550 **Asymmetry and Similarity Phenomena in Backwards Masking Experiments Suggest Reentrant Processing.**

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Non-linear effects can be observed in fast backwards-masking psychophysics experiments. Such experiments show that: 1) when targets and masks are similar they require longer processing times 2) patterns with unique features are processed quicker, displaying an asymmetry 3) these properties can also determine whether masking functions follow monotonic or U-shape curves. Hypotheses regarding the structure of neural processing involved in rapid image presentations range from pure feedforward models to models with lateral connections and top-down reentrant feedback. Although the prevailing interpretation has been that for very fast image presentations under effective masking, a feedforward model is adequate, there is now growing evidence against this possibility. It remains unclear if the earliest signals of object detection in the brain are connected with object identification or more general statistical properties of the signal and 150ms may be enough time for limited feedback processing. Furthermore it is possible that simultaneous processing of both the target and mask continues until the person responds. We construct and test a set of hypotheses for simultaneous and serial processing of the target and mask while evaluating the consequences of different cortical dynamics on speed of sight psychophysics experiments. We demonstrate that models whose dynamics are essentially feedforward HMAX-like cannot easily account for effects of differential masking and asymmetries in image sequences, because they are not well-suited for simultaneous processing. We then show that a simple model with top-down feedback naturally accounts for these properties, suggesting that even for very short presentation times reentrant connections play an important role in visual perception in humans.

33.551 **Activation of complex stimulus-response mappings without visual awareness**

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Conscious representations are generally thought to entail deeper or more complex forms of information processing. Although several priming studies support this claim, other studies show unconscious semantic processing or even unconscious complex decision making. In the current study we provide evidence that such discrepancies might be due to differences in information processing times as opposed to consciousness. In three experiments, we sought to disentangle the role of awareness from prime processing using complex stimulus response (SR) mappings, where physically dif-

ferent stimuli are mapped to the same response. In each experiment, primes were rendered invisible using metacontrast masks, which also served as the targets. When primes were physically different than targets, they were either response congruent or response incongruent. In the first experiment, we obtained faster reaction times for physically different stimuli when they were mapped to the same response. Forced-choice prime discrimination confirmed that participants were unaware of the primes. These results provide evidence for unconscious priming with complex SR mappings. Our results are different from those of a previous study that used a shorter prime to mask interval (Ro, T., Singhal, N. S., Breitmeyer, B. G., & Garcia, J. O. (2009). *Attention, Perception & Psychophysics*, 71(1), 95-103.), suggesting that complex stimulus response mapping arises with longer processing times. In the second experiment, using multiple prime-mask intervals and a subjective measure of awareness, we measured stronger priming effects for longer prime-mask intervals under conditions of unawareness. In the third experiment we show that unconscious priming occurs even at very brief processing durations if perceptual similarity between the stimuli is increased. These results provide strong evidence for unconscious priming with complex SR mapping and demonstrate the importance of allowing for sufficient prime processing under unaware conditions. TEST

33.552 Neural responses to predictably changing visual motion patterns in macaque medial superior temporal cortex

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The transfer of information from the retina to the cortex takes time, which complicates the interaction of an organism with its dynamic environment. In principle, the adverse effects of latency could be minimized by predicting future visual input based on the recent past. We investigated whether such predictive responses exist in the dorsal aspect of the medial superior temporal cortex (MSTd). We presented optic flow stimuli that changed predictably along a trajectory in spiral space. We first defined the onset latency as the time between the appearance of the stimulus on the screen and the peak of the onset response. Because the starting position of the stimulus was randomized, the onset response could not involve successful prediction, and served as a baseline measure of latency. Second, we calculated the steady-state latency as half the difference between the time of the peak response to one sequence of optic flows and the time of the peak response to the reversed sequence. In our sample of 89 neurons, the mean steady-state latency was 18 ms (SD=52), much shorter than the mean onset latency of 46 ms (SD=17; paired t-test $p < 0.001$). The dynamics of the transition from onset latency to steady-state latency was very rapid; neurons operated at the short steady-state latency within 100 ms after stimulus onset. This finding is consistent with a rapid prediction of the future state of a predictable stimulus. The mechanism for these effects could include short-term, pattern specific adaptation. We are currently investigating whether these effects reflect a flexible and functional compensation for latency that could facilitate sensorimotor interactions of the organism with its surroundings.

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33.553 The temporal order judgment task and achromatic stimuli can reveal the color-motion asynchrony

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The color-motion asynchrony was originally discovered in a visual stimulus that changes color (e.g., red and green) and direction of motion (e.g., upward and downward) rapidly and repeatedly. In order for a human to perceive those changes taking place simultaneously, direction change must precede color change by about 80 ms (Moutoussis & Zeki, 1997). This color-motion asynchrony was recently shown by the correspondence task with stimuli that change color and motion just once, but not by the temporal order judgment task (Linares & López-Moliner, 2006; Self et al., 2010). The purposes of this study are 1) to see whether the temporal order judgment task can also show the color-motion asynchrony by eliminating the artifact in the earlier studies and 2) to examine whether the luminance change alone can show the similar effect. We employed the method of constant stimuli. Tasks were either the correspondence task or the temporal order judgment task. The color/luminance of the stimuli were 1) equiluminant (28 cd/m²) colors varied along the L/(L+M) axis, 2) equiluminant (28 cd/m²) colors varied along the S/(L+M) axis, or 3) equal energy white at 8 cd/m² and 40 cd/m². The results from five observers showed that the color-motion asynchrony was observed in both tasks. The mean asynchrony for the cor-

respondence task was 97 ms (SEM=15) and that for the temporal judgment task was 66 ms (SEM=13). A two-way ANOVA (task x color/luminance) with repeated measures showed that this difference between the tasks was significant, $F(1, 4) = 7.905$, $p = .048$. Further, the results revealed that the luminance change also showed the color-motion asynchrony. Therefore, the color-motion asynchrony is not strictly limited to the color change in an equiluminant plane. Rather, the phenomenon needs to be investigated in a broader context including the achromatic system.

33.554 It Is Not Just Guessing: Electrophysiological Evidence For An Order-Reversal Illusion In RSVP

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Subjects can easily report two consecutive targets during RSVP at an SOA of 100ms, however, these targets are often reported in the wrong order. It is frequently assumed that these errors reflect the integration of both items into a single event, with the consequent loss of order information. This hypothesis is supported by EEG findings that the ERP produced by two rapidly presented targets is a single P3 potential. However we present new neurophysiological evidence that this hypothesis is incorrect. These new data suggest that subjects are seeing the targets in the wrong order on some of the trials rather than simply guessing incorrectly. We compare ERP traces recorded during encoding of two letter targets in a stream of digit distractors at an SOA of 80ms and we find a subtle but highly consistent deviation in the P3 produced by trials with incorrect order information that is well predicted by a computational model (Wyble, Bowman & Nieuwenstein 2009). The comparison of ERPs between correct and incorrect trials suggests that attentional deployment in response to the targets is delayed on the incorrect trials. The second target is then encoded more rapidly than the first one. Thus the data provide strong electrophysiological support for the idea that order reversals in RSVP are the result of prior entry by the second target. This conclusion is further supported by ongoing behavioral experiments showing that subjects' ability to report the order of two targets may become worse than chance at 40 ms SOA. These results reveal important details about the parallel processing of two targets that is thought to occur during lag 1 sparing in the attentional blink. Furthermore, this evidence supports the theory that order-reversals in RSVP are a genuine illusory percept rather than the outcome of event integration. Wyble Bowman & Nieuwenstein (2009) *JEPHPP*.35(3):787-807

33.555 The flash-lag effect for luminance change: reduction in terms of active control depends upon the directional consistency between hand movement and luminance change.

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Observer's active control of the stimulus movement by the use of computer mouse reduces the flash-lag effect (Ichikawa & Masakura, 2006 *Vision Research*, 2010 AP&P). Results of these previous studies suggested that the reduction of the flash-lag effect for the moving stimulus depends upon the learning of the directional consistency between the hand movement and stimulus movement in everyday-computer use. In order to examine the effects of directional consistency between hand movement and visual stimulus change, we measured the flash-lag effect for the luminance change in which there was no intrinsic directional relationship between hand movement and luminance change in computer use. In the active condition, the luminance of the visual stimulus was controlled by the use of computer-mouse while, in the automatic condition, the luminance changed automatically. In the active condition, there were two conditions which concerned with the directional relationship between hand movement and luminance change in visual stimulus. In the consistent direction condition, the luminance increment and decrement were always coupled with backward and forward hand movement, respectively. In the inconsistent direction condition, the luminance increment and decrement were respectively coupled with backward and forward hand movement in half of the trials while they were respectively coupled with forward and backward hand movement in the remaining trials. We found that the reduction of the flash-lag effect in the active condition was restricted to the consistent direction condition. The observers who had participated in sessions with the inconsistent direction condition showed no significant reduction of the flash-lag effect in additional observation with the consistent direction condition. These results suggest that the proprioceptive signal to control the visual stimulus would

be effective in reducing the flash-lag effect in terms of motor-visual cooperation only when the directional relationship between hand movement and stimulus change is always consistent.

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33.556 Subject criterion can explain Bloch's law

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The apparent contrast of a visual stimulus varies as a function of duration, a phenomenon known as temporal integration. There are two accepted principles to explain the role of stimulus duration in perceived contrast. Bloch's law states that below a critical duration, apparent contrast is a function of both stimulus intensity and duration, while above this critical duration, apparent contrast plateaus. Contrary to Bloch's predictions, Broca and Sulzer proposed that apparent contrast is maximized for specific stimulus durations, and that smaller or greater durations result in lesser apparent contrast. Despite the incompatibility between these two models, the literature on the topic contains studies supporting both of them. We hypothesize that the source of this discrepancy may be that previous studies were conducted on experienced subjects who knew the proposed hypotheses (i.e. the authors), and that no previous study was properly controlled for subject criterion. To address these concerns, we designed a 2-AFC task that counterbalanced stimulus dynamics and controlled for subject criterion. Five naive subjects were presented with Gabor patches of different contrasts and durations over a 50% grey background and were asked to report which of them had higher contrast. Our results support the model proposed by Broca and Sulzer: when the stimulus duration had a value between 50-100 ms, subjects experienced higher apparent contrast. When the same subjects repeated the same experiment without controlling for criterion, the peak in the perceived contrast tended to diminish or disappear, in a way similar to Bloch's predictions, suggesting that subject criterion could be causing the conflict in previous studies.

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33.557 Novel MR Safe Stimulator With Six Color Channels at Accurate High Temporal Frequencies

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Commercial displays have three significant limitations for temporal and chromatic neuroscience measurements: (a) severe contrast attenuation for frequencies over 50Hz, (b) only three color primaries, and (c) modest maximum intensity and dynamic range. To study temporal processing and adaptation within isolated color channels, we developed a new, uniform-field display apparatus, suitable for both psychophysics and magnetic resonance (MR) imaging. The display consists of an Arduino Mega micro-controller board, six high-intensity LEDs (LUXEON® Star), precise constant-current controllers (LuxDrive™ BuckPuck), optical fiber light pipes and a MR-compatible eyepiece. The micro-controller runs a custom (open-source) firmware that receives simple commands from a host computer over a USB connection. The waveform generation, temporal envelope, and gamma-correction are computed on the microcontroller. The waveform play-out and pulse-width modulation (PWM) are precisely controlled by the micro-controller's 16-bit timers. The LED intensity is refreshed at about 2000 Hz with 12-bit PWM intensity control. Therefore, the device produces accurate sine wave flicker at temporal frequencies over 100 Hz. Photons from the LEDs go through plastic optical fiber bundles and are homogenized by two diffusers (LSD®, Luminit™) at the eyepiece. Through an aspheric lens attached with the eyepiece, a subject can observe spatially uniform flickering stimuli at a visual angle of over 45 degrees radius. The spectral peaks of the six LED colors are 447.5nm (Royal Blue), 470nm (Blue), 505nm (Cyan), 530nm (Green), 590nm (Amber) and 627nm (Red). Mean luminance through the eyepiece is 720 cd/m². (For more details, see: <http://vistolab.stanford.edu/newlm/index.php/LedFlicker>) With six color channels we can modulate photopigments in the rods, the three cone classes or the intrinsically photoreceptive ganglion cells either separately or in combination across a

wide range of temporal frequencies and mean intensity levels. The apparatus overcomes temporal and chromatic limitations of commercial displays to generate novel psychophysical and neuroimaging measurements.

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Sunday Afternoon Talks

Perceptual organization

Sunday, May 8, 2:30 - 4:15 pm

Talk Session, Royal Palm 1-3

Moderator: Fred Kingdom

34.11, 2:30 pm

Tangent bundle contour completion with early vision mechanisms

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Visual contour completion is a classical vision problem which has been explored for over a century. Efforts to model the shape of the completed contour has been made in the past decades mainly in an "axiomatic" fashion, i.e., by predefining a set of "desired" perceptual/geometrical properties (e.g. minimum total curvature in Ulman, 1976; Mumford, 1994, or minimum total change of curvature and roundedness in Kimia, 2003) and then seeking the curve that satisfies them. However, some of these perceptual axioms are debatable (e.g. roundedness in Singh & Fulvio, 2005, scale invariance in Gerbino & Fantoni, 2006) and some of them are difficult to measure psychophysically.

Recently, we suggested to model the shape of the completed contour from the perspective of the primary visual cortex while using its abstraction as the unit tangent bundle space $R^2 \times S^1$. Curves in this space represent the activation pattern of orientation selective cells due to real or completed image contours, and the pattern of fewest active cells (i.e. the curve of minimal length) is sought for, assuming the completion mechanism aspires for a minimum energy state (Ben-Yosef & Ben-Shahar, 2010). While previously we proposed a rigorous mathematical analysis for this principle and an exploration of its derived visual properties, here we propose a biologically-plausible mechanism and computational model for the computation of the corresponding completed curve with known early visual mechanisms. We then present results of our model in comparison to reported completions by human observers (e.g., Fulvio et al. 2008) and show how they match with unprecedented accuracy to support our curve completion theory.

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34.12, 2:45 pm

The Modulation of Illusion Susceptibility by TMS in Right SPL Demonstrates its Role in the Processing of Global, but not Local, Contextual Information

Paul Dassonville¹(prd@uoregon.edu), Benjamin D. Lester¹; ¹Department of Psychology and Institute of Neuroscience, University of Oregon

Previous work (Walter & Dassonville, 2008) has shown that predominantly right-lateralized regions of superior parietal lobule (SPL) are more active when participants make location judgments in the presence of an illusion-inducing visual context (the induced Roelofs effect), compared to when the same judgments are made in isolation. However, the specific role played by these parietal regions in encoding contextual information remains unclear. We assessed the effects of suppressing the neural activation within these parietal regions by applying slow (1 Hz) repetitive TMS. Participants (n = 13) performed an orientation judgment in the context of the Rod-and-Frame illusion (RFI, in which the perceived orientation of a target line is biased by the global context provided by a large tilted frame) or the Simultaneous Tilt illusion (STI, in which the perceived orientation of a target line is biased by local interactions between the target line and a surrounding array of tilted lines). Accuracies in these judgments were assessed before and after 10 minutes of rTMS applied, in separate sessions, to the right SPL, left SPL, or a control site at the vertex. If right SPL is an active processor of visual context, suppressing it should lead to a drop in illusion magnitude. Alternatively, if right SPL is involved in an active inhibition of the effects of context, an increase in illusion magnitude is expected. Participants' sus-

ceptibility to the illusion-inducing effects of the RFI decreased after TMS over right SPL, compared to left SPL and vertex. In contrast, susceptibility to the STI was unaffected by TMS, regardless of the stimulated region. In no region did TMS cause a decrease in the precision of the participants' perceptual reports for either illusion. These findings indicate that right SPL is involved in the active processing of global, but not local, contextual information in the visual image.

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34.13, 3:00 pm

Spatial properties of texture-surround suppression of contour-shape coding

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Aim. Although evidence suggests that contour-shapes and texture-shapes are processed by different mechanisms, they nevertheless interact in an important way. Specifically, textures can inhibit the processing of the shapes of contours they surround; this is termed 'texture-surround suppression of contour-shape'. How does this suppression operate and what is its spatial extent? Method. Subjects adapted to pairs of sinusoidal-shaped textures or of single contours that differed in shape frequency, and the resulting shift in the apparent shape-frequency of single-contour test pairs was measured. All contours consisted of strings of Gabor microelements that were oriented either parallel ('snakes') or perpendicular ('ladders') to the path of the contour. The texture adaptors consisted of a central contour and a surround made of a series of contours arranged in parallel. We varied (i) the number of contours in the surround-texture and (ii) the orientation of Gabors in the texture-surround relative to the central-contour. Results. We found that (i) for extended texture-surrounds, the coding of snake contour-shapes is strongly suppressed by snake surrounds, and ladder contours by ladder surrounds, but the suppression is much reduced if the center and surround contours are of opposite type. (ii) Both snake and ladder surrounds with 7 contours or less have the same suppressive effect on a ladder contour. (iii) Near ladder-surrounds suppress the coding of snake contour-shapes more than do near snake-surrounds. Conclusion. There are two components to texture-surround suppression: one operates locally, is broadband in orientation and disrupts contour-linking, the other is spatially extended and prevents the shape of the contour from being processed as a contour.

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34.14, 3:15 pm

Integrated Bayesian estimation of 3D shape and figure/ground

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Shape (both 2D and 3D) and figure/ground organization have usually been treated as disparate topics, but the representation of contour shape and the assignment of border ownership (figure/ground) are well-known to be intimately related. In this work we present Bayesian techniques for estimating them jointly in an integrated fashion. In previous work, we have developed a framework for Bayesian estimation of the shape skeleton, that is, for identifying the skeletal (medial-like) structure that best "explains" a given shape as the outcome of a stochastic growth-like process. Here we generalize this computational framework to encompass multiple contours with unknown border ownership, building upon two premises supported by empirical findings: (1) that skeletal structure tends to "draw" border ownership, and (2) that border ownership can vary along the length of a contour depending on local geometry. In the expanded framework, the computational goal is to estimate not just a single skeleton but a set of skeletons that, collectively, best explain the ensemble of image contours, including the figural polarity

at each contour point. In the maximum a posteriori (MAP) estimate, each contour point is perceptually “owned” by the side whose skeletal structure best explains it; that is, contours are owned by their apparent interiors. Moreover, by expanding the data to be explained to include T-junctions, the MAP interpretation can encompass depth differences, resulting in an estimate of the 3D (nonplanar) structure of each skeleton. These 3D skeletons can then be “inflated” to recover a rudimentary estimate of 3D shape based on estimated skeletal structure. The result is an integrated Bayesian estimate of 3D shape and f/g together, which accounts for key perceptual intuitions and agrees with a variety of psychophysical data.

Supplemental details and figures can be found at rucss.rutgers.edu/~jacob/demos/shape.html

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34.15, 3:30 pm

Motion attached to a new surface is easier to detect

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The suprathreshold appearance of attributes such as color and motion depends not only on the early processing of specialized detectors, but also on how the image is segmented into surfaces. Detection thresholds, however, are thought to primarily depend on the activity of early detectors. Contrary to this view, here we show that motion detection sensitivity is enhanced when motion is perceived as belonging to a new surface. Base line condition: a field of random dots, consisting of dots moving to the left or to the right and dynamic noise dots, was displayed for 133 ms. This signal period was preceded and followed by 500 ms periods of dynamic noise dots. A tone was presented at the commencement of the signal period to minimise temporal uncertainty about the signal. New surface condition: during the signal period, four pac-men, arranged to form an illusory Kanizsa square, suddenly appeared inside the dot field. The illusory figure gave the impression that the dots it enclosed were on the new square-shaped surface. RESULTS: Motion coherence thresholds were much lower for the new surface relative to the base line condition. This sensitivity improvement did not occur if the pac-men were presented throughout, indicating that the effect is caused neither by the pac-men providing a stationary cue that facilitates the perception of relative motion, nor due to a change in size of the random dots area. Furthermore, sensitivity did not improve when visual cues not resulting in perception of a new surface were displayed during the signal period (for example, only one pacman), implying that the enhancement is not simply caused by exogenous attentional cueing. The transient Kanizsa surface may temporally segment the signal from the previous and subsequent noise dots, yielding adaptive temporal integration.

Acknowledgement: AGAUR

34.16, 3:45 pm

Efficiencies for the statistics of size

Joshua Solomon¹(J.A.Solomon@city.ac.uk), Michael Morgan¹, Charles Chubb²; ¹Optometry and Visual Science, City University London, ²Social Sciences, University of California, Irvine

Different laboratories have achieved a consensus regarding how well human observers can estimate the average orientation in a set of N objects. Such estimates are not only limited by visual noise, which perturbs each object's apparent orientation, they are also inefficient: Observers effectively use only \sqrt{N} objects in their estimates (e.g. Dakin, JOSA A 2001; Solomon, JoV in press). More controversial is the efficiency with which observers can estimate the average size in an array of circles (e.g. Ariely, Psych Sci 2001; Chong et al, P&P 2008; Myczek & Simons, P&P 2008). Of course, there are some important differences between orientation and size, nonetheless it seemed sensible to compare the two types of estimate against the same ideal observer. Indeed, quantitative evaluation of statistical efficiency requires this sort of comparison (Fisher, 1925).

Our first step was to measure the noise that limits size estimates when only two circles are compared. Our results (Solomon & Chubb, AVA Christmas 2009) were consistent with the visual system adding the same amount of Gaussian noise to all logarithmically transduced circle diameters. Imitating and amplifying this visual noise in (uncrowded) 8-circle arrays, we have now measured its effect on discrimination between mean sizes. At present, we have results from 4 observers. Inferred efficiencies range from 37.5% to 87.5%. More consistent are our measurements of just-noticeable differ-

ences in size variance. These latter results suggest close to 100% efficiency for variance discriminations. That is, like the ideal, human observers effectively use all 8 circles in their estimates of size variance. Estimates of mean size are less efficient, but our data suggest that these estimates are limited by the same noise that limits estimates of size variance. That's where the analogy between size and orientation breaks down. For orientation, mean estimates are noisier than variance estimates (Solomon, JoV in press).

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34.17, 4:00 pm

Barrier Effects in Non-Retinitopic Feature Attribution

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Purpose. Despite retinotopic ambiguities, the visual system is capable of establishing correctly feature-object relationships. By using the Ternus-Pikler display, we have shown that perceived motion correspondences serve as the medium for non-retinotopic attribution of features to objects. The purpose of this work was to assess whether perceived motion correspondences provide a sufficient condition for feature attribution.

Methods. The stimulus consisted of a first frame containing three vertical lines, a blank ISI, and a second frame containing the three lines shifted to the right by one inter-line distance. A vernier offset was inserted to the second element of the first frame. Observers' task was to report the direction of the vernier offset for a pre-designated line in the second frame. We introduced a static “barrier” (a long vertical line) between the elements of the Ternus-Pikler display.

Results. We show that a barrier can prevent feature attribution. The assessment of perceived motion in the presence of the barrier stimulus indicates that the effect of the barrier on feature attribution is not by disrupting the motion percept itself, but instead by interfering with the process of feature attribution. The interference of the barrier with feature attribution depends in a complex way on the contrast, spatial, and temporal characteristics of the barrier.

Conclusions. Perceived motion correspondences do not provide a sufficient condition for feature attribution. Parametric properties of barrier interference indicate that this interference is not merely due to the barrier serving as a spatiotemporal reference. Instead, we suggest that feature attribution results from a non-retinotopic remapping that takes into account both dynamic and static characteristics of stimuli.

Acknowledgement: NIH R01 EY018165

Visual memory

Sunday, May 8, 2:30 - 4:15 pm

Talk Session, Royal Palm 4-5

Moderator: Julio Martinez-Trujillo

34.21, 2:30 pm

Breakdown of object-based representations in visual working memory

Daryl Fougne^{1,2}(darylfougne@gmail.com), George A. Alvarez^{1,2}; ¹Department of Psychology, Harvard University, ²Vision Lab, Harvard University

How does the structure of the environment shape what we store in working memory? Information in the world is bound into meaningful units -objects - and it is widely believed that the contents of visual working memory are bound object representations. This account suggests that, for sample displays containing more information than can be stored, we have some knowledge of all the features of stored objects, and no featural information from the subset of objects not stored. Thus, the information that is retained is determined by how features are grouped into objects. Using a task that requires multiple feature reports to a single working memory item, we find evidence against this object-based model of working memory. Our task required participants to remember the color and orientation of five isosceles triangles. After a short delay, participants were required to report the color and orientation of a single, randomly selected, probe item. The task was challenging—histograms of response error of participants' color and orientation judgments showed a high proportion of guess responses. To estimate the guess rate and precision responses, the error distributions were fit with a mixture of a uniform and circular normal distribution

(Zhang & Luck, 2008). Responses that were three standard deviations away from the target value were classified as guesses. Contrary to the predictions of object-based models, when participants randomly guessed the color they were still often quite accurate at indicating the orientation of the same item, and vice-versa. Follow up analysis and experiments show that these results were not due to failures arising during the feature report stage or the use of verbal rehearsal. In contrast to the object-based model, we propose a probabilistic model in which information for all items and all features is stored, but that representations fail probabilistically, and independently for each stored feature.

Acknowledgement: NRSA (NEI) 1F32EY020706 to D. F. and NIH-R03 MH086743 to G.A

34.22, 2:45 pm

An inhibition of return (IOR) effect resulting from directing attention within working memory

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It is well-established that a spatial attention cue can either facilitate or inhibit processing of a target stimulus presented at the cued location, depending on the stimulus onset asynchrony between the cue and target stimuli. Recently, a number of studies have begun to examine the behavioral and neural similarities and differences between perceptual attention and attention directed among items active in working memory (reflective attention). Here we explore the impact of reflective attention on perceiving a subsequently re-presented stimulus. In our first experiment, participants saw two words, followed by a cue to think back to (refresh, direct reflective attention towards) one of the words, and then a target consisting of either the refreshed word, the unrefreshed word, or a novel word. Participants were significantly slower to respond to a previously refreshed target than an unrefreshed target, an effect similar to the inhibition of return (IOR) observed in visual attention studies. However, participants remembered refreshed words better than unrefreshed words on a later surprise memory test. In a control experiment with identical stimuli, participants simply saw words re-presented instead of refreshing them, and no IOR-like effect was observed, although participants still remembered repeated words better than non-repeated words. A third study using picture stimuli instead of words demonstrated an IOR-like reflective attention effect as well, and a fourth experiment also using pictures showed that the IOR-like effect generalizes to novel exemplars from the same category as the refreshed item. These results suggest that reflective attention can result in IOR-like effects analogous to those observed for perceptual attention.

Acknowledgement: National Institute on Aging

34.23, 3:00 pm

Brain imaging of the mind's eye

Rhodri Cusack¹(rhodricusack@gmail.com), Alejandro Vicente-Grabovetsky¹, Daniel Mitchell¹, ¹MRC CBU, 15 Chaucer Road, Cambridge, UK

For millennia, philosophers and scientists have pondered on the nature of our internal mental representations. In the study of short-term memory and mental imagery, a key debate has been whether representations are analogical (i.e., with a form similar to that which comes from our eyes) or abstracted into a more symbolic code. Using multi-voxel pattern analysis (MVPA) and the new real-time fMRI method of Dynamically Adaptive Imaging (DAI), we were able to characterize the information content of our internal representations during the maintenance of short-term memory or production of imagery. Across five experiments, we have found that abstracted semantic characteristics dominate memory and imagery, and have found little evidence for analogical representation. In two of these experiments using MVPA and complex grating stimuli, we found strong retinotopic representation of attended parts of a display in occipital, temporal and parietal regions. However, during the memory period of a change detection task, although strong univariate activity persisted in parietal and ventral visual regions, retinotopy vanished. Three further experiments used DAI and MVPA with naturalistic stimuli, to characterize feature tuning in ventral visual regions. We find that during memory or imagery, the patterns of activity evoked in ventral regions are best explained by semantic rather than perceptual features.

34.24, 3:15 pm

Decoding retrieval of competing visual memories from neural reactivation

Brice Kuhl¹(brice.kuhl@yale.edu), Wilma Bainbridge¹, Marvin Chun¹; ¹Yale University, Department of Psychology

Cortical regions activated during the encoding of visual experience are often 'reactivated' when that visual experience is remembered. The present study assessed how or whether competition between memories is reflected in reactivation. Subjects (n = 20) encoded pairings of words (nouns) with images of faces, scenes, or objects. Word-image pairings were repeated twice; at a third presentation, some words were paired with new images and some with the same images. In cases where a word was paired with a new image, subjects were instructed to disregard the former image (competitor) and attempt to remember the new image (target). During retrieval subjects were presented with words and attempted to retrieve the corresponding target image and to indicate the category (face, object, scene) of the image. Multi-voxel pattern analysis (MVPA) of fMRI data measured the extent to which face-, object-, or scene-related patterns of activity elicited in ventral occipito-temporal cortex during encoding were reactivated during retrieval. Successful retrieval of target images was associated with robust neural reactivation of the target representation, but also significant – albeit weaker – reactivation of the competing representation, reflecting an influence of competing images even when target images were successfully remembered. When competing images were mistakenly retrieved (instead of the relevant target), there was robust evidence for reactivation of competing representations but no evidence for target reactivation. Additional analyses revealed (a) fronto-parietal responses during retrieval that were highest when the relative evidence for target vs. competing memories was lowest, and (b) prefrontal responses during encoding that were positively associated with subsequent reactivation of target vs. competing memories. Together, these results indicate that successes and failures in retrieving target memories amidst competing memories are borne out in neural measures of reactivation; moreover, these results point to specific prefrontal and parietal mechanisms that guide visual memory when competition is present.

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34.25, 3:30 pm

Working memory representations of visual motion direction are encoded in the firing patterns of neurons in dorsolateral prefrontal cortex, but not in area MT

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It is thought that primate dorsolateral prefrontal cortex (dlPFC) neurons play a role in the maintenance of visual information in working memory (Goldman-Rakic, 1995). It has been recently suggested that this process also involves the recruitment of neurons in early visual cortex that are selective for the stimulus features to be remembered. Supporting this hypothesis, recent fMRI studies have reported that the contents of visual working memory can be decoded from patterns of BOLD signals in visual areas (Harrison and Tong, 2009). However, because fMRI does not directly measure the neurons' spiking activity, it remains controversial whether this effect is attributable to variations in the firing patterns of neurons, or in the amplitude of other signals such as local field potentials. Here, we investigate this issue by recording the spiking activity of single neurons simultaneously from the dlPFC (n=53) and early visual area MT (n=33) of two rhesus monkeys during a working memory task requiring them to remember the motion direction of a sample random dot pattern and match it to the direction of one of two test patterns serially presented inside the neurons' receptive field. During the memory period, the activity of most dlPFC remained above or below baseline, and approximately 1/6 of the neurons showed sustained tuning to the remembered direction. In all of the recorded MT neurons, activity remained at baseline levels and direction tuning was not present throughout the memory period. Our results show that working memory representations of motion direction are encoded in the firing patterns of neurons in dlPFC but not in MT. They further suggest that the reported patterns of BOLD activation in visual cortex reflecting the contents of working memory may originate from changes in other signals such as local field potentials rather than spiking activity.

Acknowledgement: Canadian Institute of Health Research & EJLB Foundation

34.26, 3:45 pm

An Ideal Observer Analysis of Visual Short-Term Memory: Evidence for Flexible Resource AllocationChris R. Sims¹(csims@cvs.rochester.edu), Robert A. Jacobs¹, David C. Knill¹;
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Visual short-term memory (VSTM) is a central component of many human activities, but remains a poorly understood process. While previous theories have posited mechanisms intended to account for observed phenomena, in the present research we develop an ideal observer framework to uncover the expected behavior of an optimally performing memory system. We use information-theoretic constructs to characterize the optimal memory precision for visual features of a capacity-limited VSTM in a range of conditions. An ideal observer uses a flexible coding strategy determined by the task context (e.g. the distribution of feature attributes in a stimulus set), the precision of sensory signals and the number of items to be remembered. A fixed capacity limit makes specific predictions about how these factors trade-off in determining memory task performance. To evaluate the predictions of our analysis, we conducted two experiments to measure the precision with which subjects remember stimulus features (visual location or orientation) in arrays of varying set size and in conditions with different variances of the feature properties to be remembered. Subjects' precision decreased with increasing set size. For each set size, it also decreased with increasing feature variance. Both of these results are predicted by an ideal observer that flexibly allocates a continuous memory resource. Subjects' guess rates, however also increased with increasing set size, even at the smallest set sizes, indicating that subjects did not evenly distribute memory resources across all items in a display. We demonstrate that both findings fit naturally within our ideal observer framework, with the additional assumption that although VSTM has a fixed capacity, this capacity can be flexibly allocated among items in the scene. This generalized framework spans an entire range of models, with the continuous resource (uniform allocation among items) and discrete-slot (focused allocation on a subset of items) models at opposing extremes.

Acknowledgement: This research was supported by grants NIH R01-EY13319 to David Knill and NSF DRL-0817250 to Robert Jacobs.

34.27, 4:00 pm

Grandmother Cells, Neocortical Dark Matter and very long term visual memoriesSimon J. Thorpe¹(simon.thorpe@cerco.ups-tlse.fr); ¹Centre de Recherche Cerveau & Cognition, CNRS-Université Toulouse

How are we able to recognize visual stimuli that we have not seen for decades? This ability poses a clear challenge to current models of how information is stored in neural circuits. I propose that such long-term memories may depend on the existence of highly selective cortical neurons (effectively grandmother cells) that are so selective that they will not fire at all unless something that closely resembles the original stimulus is seen again. Simulation studies using a simple Spike-Time Dependent Plasticity rule (STDP) have demonstrated that repeatedly presenting a spatiotemporal pattern of spikes will concentrate high synaptic weights on the inputs that fire first during the pattern (Masquelier, Guyonneau & Thorpe (2008), PLoS ONE, 3, e1377). This process may only need a few tens of presentations to take effect, a suggestion supported by recent work on auditory noise learning (Agus, Thorpe & Pressnitzer (2010), Neuron, 66, 610). Once the high synaptic weights have been concentrated in this way, the addition of an inhibitory circuit that keeps the total number of active input units under strict control results in a situation where the probability of the cell firing with random input patterns can be arbitrarily low. In effect, the neuron has become extremely selective. Furthermore, if STDP is true, a cell that never fired would be able to maintain their pattern of connections intact for very long periods of time. The existence of cells with such extremely low firing rates is clearly a matter of conjecture, but the possibility that a substantial percentage of cortical neurons could constitute a form of Neocortical Dark Matter, effectively invisible to the neurophysiologist electrode, is one that merits to be taken seriously.

Acknowledgement: CNRS, ANR

Spatial vision: Natural images

Sunday, May 8, 5:15 - 6:45 pm

Talk Session, Royal Palm 1-3

Moderator: Alan Stocker

35.11, 5:15 pm

Natural scene statistics of color and rangeChe-Chun Su¹(chechunsu@mail.utexas.edu), Alan Bovik¹, Lawrence Cormack¹;
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Depth (range and changes in range) is an extremely important aspect of the environment that must be recovered from image data. Yet there has been relatively little work done on analyzing the statistical relationships between luminance, chrominance, and range, presumably due to the difficulty in getting co-registered ground-truth range data and RGB pixel data of specific natural scenes. We used a RIEGL laser scanner mounted with a Nikon D700 digital camera and a translating mount to acquire stereoscopic RGB images with co-registered range maps. These images were transformed into the more perceptually relevant CIE L*a*b* color space, and were then encoded by Gabor filter banks with different scales and orientations to roughly capture the kind of information available at the level of primary visual cortex. We examined the conditional distributions relating the luminance or chrominance information with range gradients. Of more relevance to perception, the distributions of range conditioned on the Gabor responses, whether luminance or chrominance, had very similar exponential shapes. We also examined the variations of statistical measures, e.g. mean, standard deviation, and entropy, of range gradients with the changes of the Gabor responses. Most importantly, we found that the depth difference between neighboring pixels increases as the corresponding magnitude of Gabor responses rises. Therefore, the way these range distributions changed as function of Gabor responses indicates that the visual system could, in principle, use these conditional statistics to help recover depth information from the environment. Moreover, these statistical relationships cannot only yield insight into how 3D structure in the environment might be recovered from image data, but may also be applied to various image and video engineering applications, e.g. image de-noising and restoration, and quality assessment of 3D images and video.

35.12, 5:30 pm

High-order statistics for optimal point prediction in natural imagesWilson Geisler¹(geisler@psy.utexas.edu), Jeffrey Perry¹;
¹Center for Perceptual Systems, University of Texas at Austin

Studies of natural signals often focus on measuring second order statistics—the covariation between pairs of feature properties. Efforts to move beyond second order statistics typically assume particular forms of signal invariance in order to simplify the statistical measurements. However, restricting measurements to second order statistics or assuming particular forms of invariance might miss fundamental statistical structure that is crucial for characterizing natural signals. We show that it is practical to directly measure higher order statistics using the simple strategy of estimating moments along single dimensions, conditional on the values along other dimensions. Although this conditional moments approach is only practical for distributions of modest dimension, it has some unique advantages. First, univariate conditional distributions for local image properties are frequently unimodal and simple in shape, and thus the first few moments capture much of the shape information. Second, estimating conditional moments only requires keeping a single running sum for each moment, making it practical to use essentially arbitrarily large numbers of training signals (in our case over 1010) and hence to measure higher order statistics with higher precision. Third, it is relatively straightforward to specify bayesian optimal estimators from conditional moments (the MMSE estimator is the first conditional moment). Fourth, conditional moments can be measured recursively in a hierarchical fashion, allowing the approach to be extended to higher numbers of dimensions than would otherwise be practical. Third, fourth and fifth order statistics (and recursive statistics) were measured for nearby points in a large collection of calibrated natural images. These measurements reveal highly systematic statistical regularities not reported previously. The importance of this higher order structure is demonstrated

by showing how it can be exploited to substantially improve image interpolation (>50% reduction in MSE over bilinear), a fundamental task in retinal decoding and in image processing.

Acknowledgement: NIH EY011747

35.13, 5:45 pm

Image correlates of crowding in natural scenes

Thomas Wallis¹(thomas.wallis@schepens.harvard.edu), Peter Bex¹; ¹Schepens Eye Research Institute, Harvard Medical School

Because of crowding among adjacent contours, object identification in the peripheral visual field is worse than predicted by acuity alone. Natural visual environments are full of contours and must therefore be profoundly crowded. We examined sensitivity to peripheral spatial structure in natural scenes by asking observers to detect the presence of patches of "dead leaves": ellipses of random size, aspect ratio and orientation superimposed onto greyscale natural images to produce naturalistic edge structure with the same average luminance and contrast as the image patch they replaced. Three observers identified the location of the dead leaves patch relative to fixation (N, S, E or W) at three eccentricities (2, 4 and 8°), with the size of the patch under the control of an adaptive staircase. Size thresholds increased with eccentricity, consistent with the eccentricity-dependence of crowding. A reverse correlation analysis was used to determine which properties of the underlying image were correlated with patch detection. For each of approximately 10000 image trials per observer, the local luminance, rms contrast, edge density, orientation, orientation variance and amplitude spectrum slope were computed at 8 spatial scales (Gaussian σ from 0.3 to 4 degrees). Differences of image statistics between spatial scales allowed the comparison of different center/surround combinations. These image statistics were then used as predictors in a logistic regression analysis of trial-to-trial performance. At eccentricities of 2 and 4 degrees, observers' performance was best predicted by the difference between the smallest center and the largest surround, whereas at 8 degrees the best-fitting models compared coarse spatial scales. Regression coefficients highlight the importance of contrast, edge density, orientation variance and amplitude spectrum slope in predicting performance, with luminance and orientation contributing little to the model. These models allow prediction of when crowding may occur in a given natural image.

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35.14, 6:00 pm

Decoding natural signals from the peripheral retina

Brian McCann¹(brian.mccann@mail.utexas.edu), Wilson Geisler¹, Mary Hayhoe¹; ¹Center for Perceptual Systems, University of Texas at Austin

Peripheral ganglion cells have lower density and larger receptive fields than the fovea. Consequently, the quality of the visual signals that they relay is reduced. The information contained in peripheral ganglion cell responses can be quantified by how well they predict the foveal ganglion cell responses to the same stimulus. Here, we developed a model of human ganglion cell outputs combining existing measurements of the optical transfer function with the receptive field properties and sampling densities of P ganglion cells. Next, we simulated a small spatial population of P-cell responses to 1° patches from a large sample of luminance-calibrated natural images. For each image patch we simulated population responses for retinal eccentricities ranging from 0°-15°.

Spatial phase and orientation are largely preserved by circularly symmetric receptive fields. Therefore, we characterized the population of ganglion cell responses by their radially-averaged spatial power spectrum. A two parameter function adequately summarized these power spectra. One parameter describes the falloff of power with spatial frequency; the other describes the variance of the responses across cells in the population (power per ganglion cell). We found that the variance was constant with retinal eccentricity on average, but for a given patch the falloff parameter in the periphery was strongly predictive of the foveal variance. For example, at 15° eccentricity the percent error in the Bayes optimal prediction of foveal variance improved by a factor of 2 by taking into account both peripheral falloff and variance, as opposed to peripheral variance alone.

Humans could exploit this information when decoding peripheral P-cell responses. Decoding in this way might facilitate various known perceptual constancies (e.g., contrast and blur constancy) creating the common percept of a sharp peripheral image. Further, it could reduce the number of eye movements necessary to encode the image.

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35.15, 6:15 pm

Shape and Albedo from Shading using Natural Image Statistics

Jonathan Barron¹(jonbarron@gmail.com), Jitendra Malik¹; ¹EECS, UC Berkeley

A human observer perceives the Mona Lisa neither as paint on a flat canvas nor as a strange shape with uniform albedo, but instead as a familiar woman with light skin and dark hair. This suggests a statistical formulation of the problem, where certain shapes and albedos are more likely than others. We address the problem of recovering the most likely albedo and shape that explain a single image, using techniques from natural image statistics, but applied separately to the albedo and geometry of a scene.

Our technique is based on multiscale generalizations of the Roth & Black Field of Experts, which was originally proposed for image denoising. The FOE consists of a filter bank and a series of "experts" which each model the heavy-tailed response to one of the filters. A multiscale optimization algorithm is presented for searching over the space of shapes and albedos such that the likelihoods of the FOE models are maximized while the target image is exactly reconstructed. We find that multiscale priors, representations, and optimization are central to the success of our approach.

Our approach can be considered a generalization of "shape from shading" algorithms which is robust to variable albedo, or as a generalization of "intrinsic image" algorithms which explicitly recovers shape, rather than simply recovering shading. Our technique solves a superset of these two problems, and outperforms the previous best individual algorithms (such as those based on Retinex) on problems such as recovering shape and albedo from images of terrain and faces, on the MIT Intrinsic Images dataset.

Our results provide a normative model of how humans may solve this fundamental vision task, and suggests that other work in natural image statistics may aid our understanding of shape and albedo interpretation.

35.16, 6:30 pm

Benefits of a Trans-Saccadic Mask: Preventing the Desensitization Effects of Amplitude Spectrum Slope Discrimination when using Physical Masks.

Bruno Richard¹(brichard21@gmail.com), Aaron Johnson²; ¹Department of Psychology, Concordia University, CSLP (Center for Studies in Learning and Performance), ²Department of Psychology, Concordia University, CSLP (Center for Studies in Learning and Performance)

Studies that have explored our sensitivity to natural image properties, in particular to the amplitude spectrum slope, and have demonstrated that we are more sensitive to a specific range of the spectrum (1 - 1.3), while insensitive to steep (>1.6) or shallow (<0.7) slopes. In a recent study (Johnson et al, submitted), where we assessed the perception of the amplitude spectrum, stimuli presented without a surround did not show increased sensitivity to values between 1 and 1.3. This lack of change in the thresholds could be due to the influence of the mask, therefore, we assessed the effects of masks on the amplitude spectrum discrimination tasks. The physical properties of masks, which are necessary to prevent direct comparison of stimuli, can have complex interactions with discrimination, changing individual sensitivity and improperly reflecting the visual systems' ability to discriminate changes. To address this issue, we introduced saccades - which also generate a suppression mechanism - as a potential replacement for physical masks when measuring sensitivity to image statistics. Retinal blurring, caused by saccade, can be used to remove stimuli from the retina. We measured discrimination for 5 amplitude spectrum values (0.4 -1.6) with 5 different types of masks: no-mask, random noise, amplitude slope values of 1.0 and 2.0, and finally an adaptation of the trans-saccadic masking procedure (Irwin & Zelinsky, 1992). The results showed that thresholds are lowest when no mask was used (0.13 - 0.20), and when the stimulus and mask values were similar in amplitude, discrimination was facilitated and thresholds reduced (0.15, 0.11, 0.19). In addition, thresholds for the trans-saccadic mask were between the no-mask and physical masks values (0.08 - 0.16). This finding

suggests that trans-saccadic masking is capable of effectively masking the stimuli, and may reflect a more ecologically valid sensitivity to discriminating changes in the amplitude spectrum slope.

Acknowledgement: NSERC

Face perception: Neural mechanisms

Sunday, May 8, 5:15 - 6:45 pm

Talk Session, Royal Palm 4-5

Moderator: Galit Yovel

35.21, 5:15 pm

Mirror-image confusion in human high-level visual cortex

Vadim Axelrod¹(vadim.axelrod@gmail.com), Galit Yovel¹; ¹Department of Psychology, Tel Aviv University

Confusion between mirror-symmetric images has been demonstrated in children, adults, mammals and even invertebrates. For example, children frequently confuse mirror-symmetric letters, such as 'b' and 'd'. Mirror confusion has also been reported for head views when subjects failed to remember the direction of Abraham Lincoln's profile on a US penny coin. Several single-unit recording monkey studies in inferior temporal cortex and banks of the superior temporal sulcus reported the possible neural mechanisms of mirror-image confusion of simple shapes, objects and heads. However, to date no evidence for such representation has been shown in the human brain. In a functional MRI study we presented subjects with images of human faces in five different views (left/right profile, left/right half profile and front). We used multi-voxel pattern analysis (MVPA) technique to decode the direction of head view from neural activity. High-level visual areas (Fusiform Face Area and Lateral Occipital Complex) showed worse discrimination between mirror-symmetric head views (e.g., right-left profiles) and best discrimination between profiles and front faces. These findings indicate similar neural representation for mirror-symmetric head views. Notably, this pattern was not observed in early visual cortex, which showed best discrimination of mirror-symmetric profiles that decreased monotonically as a function of the angle difference between head views. These findings complement a recent single-cell recording study of face-selective patches in the macaque, which revealed large proportion of mirror-symmetrically tuned neurons in the anterior lateral face patch. Taken together, these results highlight the importance of such bi-modal tuning to mirror symmetric images as an intermediate step before the generation of an invariant representation. Finally, mirror-confusion for face views was not limited to face-selective areas, consistent with the idea that mirror confusion is a general shape processing phenomenon rather than a face-specific effect.

35.22, 5:30 pm

The role of face-selective and object-general mechanisms in the face inversion effect: A simultaneous EEG-fMRI study

Boaz Sadeh¹(boazsadeh@gmail.com), Tamar Goldberg¹, Chen Avni¹, Michel Pelleg¹, Galit Yovel¹; ¹Department of Psychology Tel Aviv University

The face inversion effect (FIE) refers to the greater difficulty we have in recognizing inverted than upright faces. It has been suggested that inverted faces are processed like non-face objects. Event-related potential studies consistently show an increase in the amplitude of the face-selective N170 component to inverted relative to upright faces (N170-FIE). Here we tested two hypotheses that may account for the increased response of the N170 to inverted faces. According to a quantitative hypothesis inverted faces exploit the same mechanisms used for upright faces but with more computational effort. This hypothesis predicts that the increased N170 amplitude to inverted faces is mediated by face-selective mechanisms. According to a qualitative hypothesis, inverted faces engage additional processing mechanisms such as object-general mechanisms. This hypothesis predicts that the increased N170 amplitude to inverted faces is mediated by object-general mechanisms. To test these two hypotheses we conducted simultaneous EEG-fMRI experiment in which we presented upright and inverted faces in an event-related design. For each subject we also localized face-selective and object-general areas based on a functional localizer scan. Following removal of MR-artifacts from the EEG signal we measured the response of the N170 to upright and inverted faces and computed an N170-FIE index for each subject. Similarly, we measured the response of face-selective and object-general areas to upright and inverted faces and computed an fMRI-

FIE index for each area of each subject. Correlational analyses revealed that the N170-FIE was strongly correlated ($r = .8$) with the FIE in object areas but not with the FIE in face-selective areas. These findings are consistent with the qualitative hypothesis and suggest that object processing mechanisms are involved in the processing of inverted faces as early as 170ms after stimulus onset.

Acknowledgement: German-Israeli foundation for young investigators

35.23, 5:45 pm

Contribution of Anterior Temporal Lobe in Recognition of Face and Non-Face Objects

Shahin Nasr¹(shahin@nmr.mgh.harvard.edu), Roger Tootell¹; ¹NMR Martinos Center, Massachusetts General Hospital, Harvard Medical School, Charlestown, MA 02129

Previous fMRI studies showed several face-selective areas in human visual cortex, including the Fusiform Face Area (FFA). Following results in macaques, recent fMRI studies also demonstrated face-selective regions in the human anterior temporal lobe (ATFP), which may be involved in higher-level functions such as face recognition. To clarify the contribution of category-selective regions within anterior temporal lobe during recognition, we measured fMRI activity during a 1-back recognition task ($n=14$), based on computer-generated faces and houses relative to a 1-back dot-location task, using identical stimuli. As controls, we tested the effects of: 1) face and house rotation in depth and 2) face contrast reversal; both factors are known to affect recognition. The level of task difficulty was controlled by independently manipulating the contrast of the faces, houses and dots. The facial recognition task produced higher activity confined to FFA and ATFP, relative to the 1-back dot-location task. Consistent with our hypothesis, fMRI activity in ATFP was more related to recognition compared to FFA: 1) Over all facial recognition conditions, subjects' response accuracy was significantly correlated with BOLD amplitude in ATFP, but not in FFA; 2) Compared to house recognition, higher response modulations were found during face recognition in ATFP, but not in FFA. Otherwise-equivalent house recognition task produced a quite different pattern of activity. House recognition strongly increased activity in previously undescribed patches within the anterior temporal lobe, plus expected increases in known 'place-selective' areas such as the Parahippocampal Place Area (PPA), Transverse Occipital Sulcus (TOS) and Retro-Splenial Cortex (RSC). These results show that face recognition activates higher-order regions within anterior temporal lobe, relatively more than previously described face-processing areas located more posteriorly in the brain. Analogously, house recognition produced activity that extended into anterior temporal lobe - but those house-recognition patches were distinct from the patches activated by face recognition.

35.24, 6:00 pm

Different neural mechanisms underlie repetition suppression to facial identity for same-size and different-size faces in the occipitotemporal lobe

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Repetition of the same stimulus leads to a reduction in neural activity known as repetition suppression (RS) (or fMRI-adaptation). RS is frequently used to probe the response properties of face-selective regions in the occipitotemporal lobe. For example, a region showing RS to the same face across changes in stimulus size is inferred to hold a size-invariant representation of facial identity. This inference is based on the assumption that RS reflects locally based 'within-region' changes such as neural fatigue. An alternative hypothesis characterises RS as a consequence of 'top-down', between-region modulation. Differentiating between these accounts is central to the correct interpretation of RS data and to understanding the functional role of different regions in the face-processing network. Using fMRI, we measured RS to familiar and unfamiliar faces within two face-selective regions of the occipitotemporal lobe - the occipital face area (OFA) and the fusiform face area (FFA). A univariate analysis revealed that both regions showed RS to images of the same face compared to different faces that persisted across changes in image size. Using Dynamic Causal Modelling (DCM) we determined how RS changed effective connectivity between these two regions. DCM demonstrated that repetition of identical face

images produced changes in forward connectivity (OFA-to-FFA) only. By contrast, RS across image-size produced changes in backward connectivity only (FFA-to-OFA). A similar pattern was found for both familiar and unfamiliar faces. These results suggest that different mechanisms underlie different forms of RS in the occipitotemporal lobe. RS to the same face image is driven by 'bottom up' changes in connectivity, consistent with neural fatigue, whereas RS across size-changes is dependent upon 'top-down' modulation. Our findings challenge previous interpretations made using fMRI RS paradigms regarding the underlying nature of neural representations in the face processing network.

Acknowledgement: Medical Research Council

35.25, 6:15 pm

An investigation of the neural basis of face individuation through spatiotemporal pattern analysis

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What neural system is responsible for face individuation and what is its structure? Extensive research on the topic offers divergent responses to the first question and rather few clues to the second. Our work deals with these issues by appealing to a sequence of multivariate pattern analyses applied to functional magnetic resonance imaging (fMRI) data. Specifically, we combine information-based brain mapping and dynamic discrimination analysis to address the first question. The goal of this analysis is to locate spatiotemporal patterns capable of supporting face classification at the individual level. Our results reveal an 'individuation network' of anterior temporal and fusiform areas. Moreover, they provide the first demonstration that the bilateral fusiform face area (FFA) responds with distinct activation patterns to different face identities. The second part of our work examines the distribution of diagnostic information across this network using recursive feature elimination. Our results show that information is distributed evenly among anterior regions. Also, an information-based network analysis suggests that one region located in the right anterior fusiform gyrus plays the role of a hub within the neural system responsible for face individuation. This work explores the specifics of distributed processing in the context of face perception; however, more generally, it speaks to its informational basis irrespective of domain in the context of functionally-defined cortical networks. Finally, our research explores ways in which the analyses above can integrate functional connectivity in order to recover the dynamics of the information flow within the face individuation network.

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35.26, 6:30 pm

Facial identity information is transferred asymmetrically between hemispheres

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Input from the left visual field (LVF) is primarily processed in the right hemisphere, while input from the right visual field (RVF) is processed in the left hemisphere. However, the two hemispheres are not functionally redundant: for example, face processing is lateralized to the right hemisphere. How can the contralateral organization of the visual system be reconciled with the asymmetric distribution of visual functions? Here we examine how high-level visual information is shared between hemispheres. Specifically, using divided visual field presentation and fMRI adaptation, we investigate the hemispheric transfer of facial identity information. While fixating centrally (as verified by eye-tracking), participants were presented with two sequential faces in the periphery. The first face was presented to either the LVF or RVF, followed by a second face to either the LVF or RVF. The second face always differed in viewpoint, depicting either the same identity or a different identity. Combining across left and right fusiform face area (FFA), we found greater identity adaptation (different - same identities) when the first face was presented in LVF vs. RVF. This pattern was apparent not only in right FFA, but also in left FFA. Indeed, left FFA did not show identity adaptation even when a face was repeated in the same preferred RVF location. Together, these findings indicate that identity information is transferred from right to left FFA, but not the other direction. Moreover, selective identity adaptation in left FFA for faces that were initially presented in LVF implies that left FFA can represent, but may not be able to compute, facial identity. In sum, hemispheric transfer from

lateralized processes may help reconcile the contralateral organization and hemispheric asymmetry of the visual system. Moreover, such transfer may help the visual system recognize objects that move between visual fields.

Color and light: Memory, language and synesthesia

Sunday, May 8, 2:45 - 6:30 pm

Royal Palm 6-8, Poster Boards 301 - 317

36.301 Color constancy in perception and memory for real illuminated objects

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Purpose: To guide behavior usefully, color perception should predict color memory. A fruit's perceived color, for example, indicates ripeness more reliably if color memory of ripe fruit is accurate. However, some previous research suggests that color memory is poor relative to perception. Why? In everyday tasks, we often must perceive objects in one scene and recall them in another. Scene changes affect color perception. Can imperfect color memory be explained by imperfect color perception? Methods: Observers viewed real painted wooden cubes in a study booth under a yellowish illuminant and selected a matching color in an adjacent test booth under a bluish illuminant. Eight cubes composed two groups (G1: pink, blue, green, orange, G2: brown, red, yellow, purple). Observers made simultaneous matches (perception) for one group, viewed the other group, waited 15 minutes, and made memory matches. To make matches, observers selected the best-matching paint from a commercial booklet of ~1000 paint samples. In the test booth, we measured chromaticity (PR 655, $u'v'$) of each cube and each selected paint sample. Results: Observers selected many different paint samples for each cube in both perception and memory conditions; thus, paint samples were discretized with sufficient resolution to detect failures of constancy. The calculated difference in chromaticity ($u'v'$) between each painted cube and the selected paint sample (both measured in the test booth) served as a measure of constancy failure. As expected, perceptual constancy for each cube was partial but not complete, and the degree of constancy varied substantially between cubes. Notably, the extent of color constancy in memory was very similar to perceptual color constancy for almost all cubes, as was the variability of color constancy. Conclusions: The data suggest that imperfect color memory for real illuminated objects can be largely explained by a propagation of imperfect perceptual constancy into memory.

Acknowledgement: NSF - BCS - 0954749

36.302 Memory colour improves colour constancy for unknown coloured objects.

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The perception of an objects' colour remains constant despite large variations in the chromaticity of the illumination; colour constancy. Hering (1920) suggested that memory colours, the typical colours of objects, could help in estimating the illuminant's colour and therefore be an important factor in establishing colour constancy. Gegenfurtner and colleagues (Hansen et al., 2006) have shown that the colour appearance of natural objects can be biased towards the typical colour and that this effect is robust under illuminant changes (Olkkonen et al., 2008). Here we test whether the presence of objects with diagnostic colours (eg., fruits and vegetables) within a scene influence colour constancy for other unknown objects in the scene. Subjects matched one of four Munsell papers (2.5p 5/4; 2.5y 5/4; 2.5b 5/4 and 2.5gy 5/4) placed in a scene illuminated under either a reddish or a greenish lamp with the Munsell Book of colour illuminated by a neutral lamp. The Munsell papers were embedded in four different scenes; one scene containing diagnostically coloured objects, one scene containing incongruent coloured objects, a third scene with geometrical objects of the same colour as the diagnostically coloured objects and one scene containing non-diagnostically coloured objects (eg., a yellow coffee mug). All objects were placed against a black background. Colour constancy was on average significantly higher (8%) for the scene containing the diagnostically coloured objects compared to the scene containing the incongruent

coloured objects and the scene with the geometrical objects of the same colour and significantly higher (4%) compared to the scene containing the non-diagnostically coloured objects. Placing one of the objects in front of the Munsell paper to guarantee local colour contrast, did not affect colour constancy. We conclude that the colours of familiar objects help in obtaining colour constancy for unknown objects.

36.303 Hybrid coding of colors: how can we unify color discrimination, categorization and memory?

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Human color perception is categorical. According to previous psychophysical studies, category has profound effects on color discrimination and memory. For example, two memory colors in different categories are more accurately discriminated than colors within an identical category (Uchikawa et al., 1996). Focal colors are remembered more accurately than non-focal colors (Heider, 1972). The mean difference between test color and recalled color increases with the delay time (Perez-Carpinell et al. 1998). Meanwhile, the activities of IT color-coding neurons differed depending upon whether the task demand is discrimination or categorization (Koida et al., 2007). Despite the accumulating evidences that suggest interaction among color category, memory and discrimination, there is no inclusive modeling study that accounts for how these different aspects of color processing emerge from the nervous system. In this study, we propose a computational model that explains the categorical effects in color perception and memory, assuming a two-dimensional space of hue and saturation. The current model considers two populations of color-coding neurons in visual cortex: 'hue-selective neurons' and 'category-selective neurons'. In the former, preferred hues are homogeneously distributed, while in the latter the preferred-hues are concentrated around some points (focal colors). We modeled the recurrent processing between the two neural populations, demonstrating the iterative Bayesian estimation of the presented color information based on the previous observations. Our model reproduced the previously reported physiological and psychophysical phenomena, which include the properties of color-coding neurons in IT cortex during categorization/discrimination, and the categorical effects and the changes of saturation in color memory. These results suggest that perceptual biases found in color processing and task-dependent modulations of neural responses are explained as natural consequences of statistically optimal estimation.

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36.304 Effects of familiar objects on color perception

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Some familiar objects have a typical color, such as the yellow of a banana. The presence of such objects in a scene is a potential cue to the scene illumination, since the light reflected from them should on average be consistent with their typical surface reflectance. We studied whether adding a familiar object to a scene improves color constancy. We used a memory color matching procedure. Subjects viewed a square reference patch for 10 seconds. This was presented against a variegated background whose mean chromaticity was that of either CIE Illuminant D65 or CIE Illuminant A. At reference patch offset, the background either remained at D65 (D65 presentation) or switched to D65 (Illuminant A presentation). After a retention interval of 15 seconds, a matching patch appeared and the subject adjusted its chromaticity to match the remembered color appearance of the reference. For each presentation illuminant, the reference patch was presented in two ways. In the "Banana" condition, an image of a banana was added adjacent to the reference patch. In the "Absent" condition, the reference patch was presented in isolation. When present, the banana was rendered under the same illuminant as the background. The banana was never present when the matches were set. We measured the shift in memory matches between D65 and Illuminant A reference presentations. For both "Banana" and "Absent" conditions, the data were consistent with partial color constancy.

In addition, there was an improvement in constancy for the “Banana” condition compared to the “Absent” condition, consistent with an effect of familiar object color. The memory matches were fairly noisy however, and the improvement in constancy was small. We plan to replicate the measurements and additional control conditions, to more conclusively determine whether a familiar object effect is the correct interpretation of the data.

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36.305 Colorfulness-adaptation influenced by recognition of images

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It has been shown that perceived colorfulness changes with adaptation to chromatic contrast modulation and to surrounding chromatic variance. It is still not clear how colorfulness perception changes with adaptation to color variations in actual environments or natural images, and mechanisms contribute to the perception. We have showed that the impression of an image was less colorful after explosion to saturated images and vice versa (APCV 2010). The effect was weaker when jumbled images were used for adaptation instead of natural images. Here, we examined how the effect of colorfulness-adaptation changes depending on adapting images, especially in relation to image recognition. The different types of image-sets were used as adaptation images; natural images consisting of natural scene or objects, jumbled images consisting of the collage of randomized color blocks cut from original images with different segmentation levels (5 by 5, 10 by 10, and 20 by 20 blocks). Five saturation-levels were examined for each image-set. A test image, which was not included in the adaptation images, was prepared for colorfulness judgment. An observer adapted to a series of images, which appeared randomly for 2 minutes, and then judged a test image at one of the eleven saturation levels. The judgment whether the test image was colorful or not was made each time a test image was presented following to 6 seconds re-adaptation. The method of constant stimuli was used. The results showed that colorfulness perception was changed by adaptation to the levels of image saturation in both natural and jumbled images. The effect was stronger with adaptation to natural images than with jumbled images. Although the effect for the different jumbling levels was different in each observer, it was generally weaker for the images with smaller blocks, implying that a colorfulness-adaptation mechanism worked better with natural images including recognizable scenes.

36.307 Inter-individual variations in color naming and the structure of 3D color space

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Many everyday behavioural uses of color vision depend on color naming ability, which is neither measured nor predicted by most standardized tests of color vision, for either normal or anomalous color vision. Here we demonstrate a new method to quantify color naming ability by deriving a compact computational description of individual 3D color spaces. Methods: Individual observers underwent standardized color vision diagnostic tests (including anomaloscope testing) and a series of custom-made color naming tasks using 500 distinct color samples, either CRT stimuli (“light”-based) or Munsell chips (“surface”-based), with both forced- and free-choice color naming paradigms. For each subject, we defined his/her color solid as the set of 3D convex hulls computed for each basic color category from the relevant collection of categorised points in perceptually uniform CIELAB space. From the parameters of the convex hulls, we derived several indices to characterise the 3D structure of the color solid and its inter-individual variations. Using a reference group of 25 normal trichromats (NT), we defined the degree of normality for the shape, location and overlap of each color region, and the extent of “light”-“surface” agreement. Results: Certain features of color perception emerge from analysis of the average NT color solid, e.g.: (1) the white category is slightly shifted towards blue; and (2) the variability in category border location across NT subjects is asymmetric across color space, with least variability in the blue/green region. Comparisons between individual and average NT indices reveal specific naming “deficits”, e.g.: (1) Category volumes for white, green, brown and

grey are expanded for anomalous trichromats and dichromats; and (2) the focal structure of color space is disrupted more in protanopia than other forms of anomalous color vision. The indices both capture the structure of subjective color spaces and allow us to quantify inter-individual differences in color naming ability.

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36.308 Mere exposure influences male colour preference, yet female colour preference is resistant to change.

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Colour preference has been related to affective responses to colour-associated objects (Palmer & Schloss, 2010). In other domains, preference for a given stimulus merely increases as a result of repeated, brief and neutral exposure to that stimulus, and these ‘mere exposure’ effects also generalise to stimuli which share similar characteristics to the exposed stimulus (e.g., Monahan, Murphy & Zajonc, 2000). Here, we investigate whether mere exposure also affects colour preference. To establish the baseline preference, one group of participants rated their preference (0-10 scale) for a set of 24 colours that were dark, light and saturated versions of eight hues (stimuli from Palmer & Schloss, 2010). A separate group of participants were then exposed to the three least liked colours (dark orange, yellow and chartreuse) 10 times for 500ms each (Bornstein & D’Agostino, 1992), whilst performing a distractor task (indicate the direction of a centrally presented arrow using arrow keys), and then rated the full set of 24 colours. There were ‘mere exposure’ effects for male but not female colour preference. Following exposure, male preference was on average significantly greater than baseline for exposed colours, and on average significantly less than baseline for non-exposed colours. Mere exposure effects also generalised to individual colours of a similar lightness to the exposed colours (greater preference for the dark colours relative to baseline), but not to colours of the same hue (saturated / light orange, yellow, chartreuse). These findings demonstrate for the first time that even brief, neutral exposure influences colour preference, possibly due to increased familiarity or processing fluency (e.g., Reber, Schwarz & Winkielman, 2004). The sex difference, and the generalisation of the effect to stimuli of a similar lightness but not hue, potentially provides insight into the psychological mechanisms and dimensions of male and female colour preference.

36.309 Preference Asymmetries in Color Pairs: Retinal vs. Perceived Size

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Does spatial organization influence preference for color pairs? We report evidence for systematic preference asymmetries, in which participants preferred two-color figure-ground displays (a small square centered on a large square) when the color of the larger region was bluer, darker, and more preferred than that of the smaller region. Results were similar for color pairs in mosaic configurations (side-by-side, separated by a gap), showing that surroundedness is not essential for preference asymmetries to arise. We clarified the nature of the relative size effect by testing the predictions of two competing hypotheses. The retinal size hypothesis posits the dominant factor to be the relative retinal area of the figure and ground regions, whereas the perceived size hypothesis posits it to be the relative area after the ground has been amodally completed behind the figure. We measured preference asymmetries for displays in which the figure’s area was smaller than (40%), equal to (50%) or larger than (60%) the retinal area of the ground to find out whether preference asymmetries would reverse when the figure’s area was larger than that of the ground, as predicted by the retinal-size hypothesis. Instead, participants preferred pairs with yellower figures on bluer grounds in all three conditions, with positive correlations between the difference in blueness between the ground and figure colors for the 40% ($r=+.63$), 50% ($r=+.58$), and 60% ($r=+.33$) configurations. Consistent with the perceived size hypothesis, the blue-yellow effect decreased as the area of the figure approached the area of the amodally-completed ground, without reversing. The same pattern was present for the difference in lightness (darker ground preferred) and in single-color preference between the

ground and the figure colors. Accordingly, aesthetic judgments of color pairs depend on the relative areas of amodally-completed regions rather than on the relative areas that are visible in the configuration.

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36.310 Biological Components of Color Preference are not Universal.

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It has been proposed that color preference is largely governed by the two cone-opponent processes that underlie sensory encoding of color, and that robust sex differences in the weighting of these 'biological components' of color preference evolved in line with sex differences in the behavioural use of color vision (Hurlbert & Ling, 2007). In support of this theory, Hurlbert and Ling found that cone-contrast between stimulus and background (L-M, S-(L+M)) explained 70% of the variance in hue preference, with a sex difference in the weighting of L-M cone-contrast for both British and Chinese samples. Here, we further investigate whether cone-contrast effectively summarizes color preference, and whether the sex difference in L-M is indeed robust and 'universal'. In a series of three experiments, we measured color preference using three different stimulus sets, and tested British, Saudi, Archis (a rural ethnic group in southern Daghistan) and Himba (a semi-nomadic ethnic group in northern Namibia) samples. Regression analyses were run on preference ratings to establish the percentage of variance explained by L-M and S-(L+M) stimulus-background cone-contrast (and CIE-LUV lightness, chroma and saturation), and to identify the weights on these different components. Results indicate that stimulus-background cone-contrast is less effective at summarising color preference the wider the gamut of the stimulus set (see also Palmer & Schloss, 2010). The sex difference in the weighting of L-M was present for the Saudi sample (females weight L-M positively, males negatively), but was not present for the Archis or Himba, and was not reliable across the three experiments for the British. In addition, Himba preference was predominantly explained by chroma (higher chroma, higher preference: 74% of the variance), rather than stimulus background cone-contrast. Overall, the findings challenge the theory that color preference is heavily and universally constrained by the biological components of color vision.

36.311 Cross-modal relations between emotional content and preference for harmony

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Previous research has shown that individuals differ in the degree to which they prefer harmonious color combinations, as measured by the correlation between ratings of preference and ratings of harmony for figure-ground color pairs (Schloss & Palmer, VSS-2007). Further research shows that this tendency is also correlated with preference for harmony in music and preference for figural goodness in spatial images for Berkeley undergraduates majoring in Psychology, Art, and Music, although specific training in a relevant domain tends to decrease a person's preference for harmony in the domains of training (Griscom & Palmer, VSS-2010). In the present study, we investigated the relationship between preference for harmony and the emotional associations of these stimuli. Participants were asked to rate various stimuli for consistency with the emotions of happy-sad and angry-calm. The stimuli were 56 color pairs, and 14 30-second clips of classical piano music, 35 images of a single dot at one of 35 positions inside a rectangular frame, and 22 Garner-type 9-dot configurations that spanned a wide range of "harmony" ratings. We found that there were strong correlations between ratings of harmony and ratings of positive emotional associations for music and color pairs: e.g., the music that was judged to be harmonious tended strongly to be judged as happy rather than sad and calm rather than angry. The same was also true of positive emotions and ratings preference for music and color pairs. In previous research music and color pairs showed the highest cross-domain correlations in preference for harmony ($r = .64$). These findings suggest that consistent cross-domain preferences for harmony may reflect, in part, a preference for the positive emotional associations evoked by harmonious stimuli.

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36.312 Color, Music, and Emotion

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Arnheim (1986) speculated that different aesthetic domains (e.g., color and music) might be related to each other through common emotional associations. We investigated this hypothesis by having participants pick from among an array of 37 colors the five colors that went best (and later the five that went worst) with each of a set of musical selections that varied in composer, tempo, and mode (major/minor). They also rated each musical selection and each color for its emotional associations (happy-sad, lively-dreary, strong-weak, angry-calm). For both orchestral music and solo piano music, systematic mappings were found between the dimensions of color and music: faster music and major mode were associated with lighter, more saturated, yellower colors, whereas slower music and minor mode were associated with darker, desaturated, bluer colors. These mappings appear to be mediated by common emotional associations, because the correlation between emotional ratings of the musical selections and emotional ratings of the colors chosen to go with them were extremely high (.90 to .98) for all emotional dimensions studied (e.g., people picked happy colors to go with happy music and dreary colors to go with dreary music). Further studies using better-controlled musical stimuli (unaccompanied theme-and-variation melodies by Mozart) dissociated effects due to instrumental timbre (piano/cello), register (high/low pitch), and note density (quarter-note theme vs. eighth-note variation), as well as tempo and mode from the specific influences of different melodic and harmonic structure in the earlier studies. The mediating role of emotion was established by obtaining analogous effects when people picked the colors that went best (and worst) with faces and body poses that expressed emotions (happy-sad and angry-calm). Similarly high correlations were obtained when the emotional ratings of the faces/gestures were compared with corresponding emotional ratings of the colors chosen to go with them.

Acknowledgement: NSF

36.313 The effects of imagined experiences of objects on preferences for colors

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The Ecological Valence Theory (EVT) posits that color preferences are caused by individuals' emotional experiences with color-associated objects (Palmer & Schloss, 2010). In support of this causal claim, Strauss, Schloss, and Palmer (VSS-2011) showed that color preferences can be changed by exposing people to affectively biased samples of colored objects that are strongly positive or negative. Exposure to positive objects of a given color (red or green) increased people's preference for that color. Here, we attempted to change individuals' preferences for red and green by having them imagine positive or negative color-associated red and green objects from their verbal descriptions. First, participants rated their preference for 37 Berkeley Color Project (BCP) colors. Second, they generated mental images from the verbal descriptions of objects and (a) selected the BCP color that best matched the imagined object's color, (b) rated the vividness of their mental image, and (c) rated their preference for the imagined object. Half of the participants imagined positive red objects (e.g., "raspberries") and negative green objects (e.g., "slime") whereas the other half imagined negative red objects (e.g., "wounds") and positive green objects (e.g., "trees"). Both groups imagined neutral objects of other colors. When participants rated their color preferences again, there was a significant interaction between the change in color preference (before vs. after mental imagery) and the valences of the imagined objects: Participants who imagined positive red objects and negative green objects increased their preference for red and decreased their preference for green relative to those who imagined negative red objects and positive green objects. These results demonstrate that even imagined color-specific emotional experiences can influence color preferences. We also report the duration of the effects of perceptual (rather than imagined) experiences by examining the magnitude of the changes after a delay of 24 hours.

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36.314 The Interaction of Synesthetic and Print Color and the Role of Visual Imagery

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Synesthesia is understood to be an automatic perceptual phenomenon paralleling print color in some ways but also differing in others. We examined this juxtaposition in a group of 13 grapheme-color synesthetes using a color priming paradigm where one of four prime types appeared for 750 msec on each trial followed immediately by a colored patch (probe). Primes induced either no color, print color only, synesthetic color only, or both forms of color simultaneously (e.g., a letter "A" printed in red that also triggers synesthetic red). Synesthetes named the probe color out loud as quickly and accurately as possible. All stimuli appeared foveally and probes were printed in the same or different color (where relevant) as that induced by primes. Replicating previous work, subjects were faster to name a probe color that was congruent with the prime color than if it was incongruent. Importantly, we found that synesthetes primed with a grapheme that induced the same print and synesthetic color showed significantly larger priming effects than when primed with either individual forms of color, suggesting an additive interaction of the two color types. Additionally, synesthetes exhibited a strong positive correlation between color priming effects (synesthetic and combination color only) and the vividness of self reported imagery as assessed with the Vividness of Visual Imagery Questionnaire (Marks, 1973). Yoked non-synesthete controls run on the same paradigm showed significant color priming effects only for primes printed in color and showed no correlations with VVIQ. These results suggest that synesthetic and print colors operate through separate but overlapping networks of color perception, with grapheme-color synesthetes possessing an extra dimension of visual space that can be bound like "normal" color but remains perceptually independent to normal color. This additional synesthetic color space may operate through a unique mechanism tied to visual mental imagery.

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36.315 Color-Grapheme Associations in Non-Synesthetes: Evidence of Emotional Mediation

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Previous research has shown that non-synesthetes have systematic associations between colors and graphemes (e.g., Simner, et al., 2005; Rich et al., 2005; Spector & Maurer, 2008). In the present study we investigated whether color-grapheme associations might be mediated by the emotional associations of the graphemes and the colors. First, participants were presented with the 26 uppercase letters of the Latin-based alphabet and 10 Arabic numerals (Helvetica font), one at a time, beside an array of the 37 Berkeley Color Project (BCP) colors (Palmer & Schloss, 2010). Their task was to select the five colors that were most consistent with the grapheme presented, followed by the five colors that were least consistent (as in Schloss, et al. (VSS-08) for color-music associations and Xu, et al. (VSS-10) for color-face associations). Next, participants rated each of the colors and graphemes along the following emotional dimensions: happy/sad, strong/weak, active/passive, and good/evil. The emotional content of the graphemes was significantly correlated with the emotional content of the colors that were associated with the graphemes for the happy/sad, ($r=.64$), strong/weak ($r=.52$), active/passive ($r=.46$), and good/evil ($r=.51$) dimensions. Participants also rated the colors and graphemes along several visual dimensions that were more weakly associated: curvy/angular ($r=.23$), open/closed ($r=.35$), balanced/unbalanced ($r=.20$), spacious/cramped ($r=.24$), and simple/complex ($r=.30$). These results suggest that the associations between colors and graphemes in non-synesthetes might be mediated, in part, by underlying emotional associations.

36.316 Type-token distinction and response time distribution analysis reveal the unique characteristic of binding in grapheme-color synesthesia

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The nature of binding in grapheme-color synesthesia addresses important issues regarding neural basis of synesthesia and visual awareness in general. Previous work with priming tasks have shown the effects of synesthetic colors, but whether synesthetic color is bound to object type or token remains unclear. Furthermore, recent data have cast doubt on whether the synesthetic priming effects are specific to synesthetic experiences. We evaluated type- and token-based color-letter binding using a task combining a synesthetic priming task and the object reviewing paradigm. A participant viewed a preview display with two achromatic letters, followed by a linking display. Then, a color patch appeared at one of the preview letter locations, and observers named the color as quickly as possible. The color matched with the synesthetic color of the preview letter at the patch location (Same-Object condition), of the other preview letter (Different-Object condition), or of a letter not presented (No-Match condition). Type- and token-based bindings are reflected by difference between No-Match and Different-Object conditions, and between Different-Object and Same-Object conditions, respectively. For control participants, letter-color associations were trained, before the object reviewing task. Although mean response times failed to reveal any significant differences between synesthetes and control participants, RT analysis with ex-Gaussian distribution revealed a distinct pattern in synesthesia group that response facilitation in Gaussian component, presumably reflecting stimulus encoding, exclusively reflected type representations. In contrast, the control group showed response facilitation in Gaussian component dominated by token representations. Thus, color-letter associations in "associator" type synesthetes are type-based without binding to object token, consistent with their subjective reports. Contrary to recent failures in showing differences between synesthetes and non-synesthetes, combination of type-token distinction and response time distribution analysis could indicate that color sensations in synesthetes are not simply the extreme form of normal associations, and cannot be attributed to demand characteristics.

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36.317 Perception of Synesthetic Colors Occurs Before Conscious Recognition of Graphemes

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We showed 2 "lower" grapheme-color synesthetes three different examples of stimuli in which the graphemes were "hidden" -as in puzzle pictures- and became visible as letters only after prolonged viewing. The stimuli were 1) 3D blocks arranged so that the space in between spelled "No Sex Causes Bad Eyes" which people take approximately thirty seconds to see. 2) An illusory letter Z defined by attached shadow in perspective which normals see as random shapes for 30 seconds. Intriguingly in both cases the subjects saw the colors accurately long before the letters and were surprised by this until the letters became visible. Subject 1 was also shown Bregmans B's which people see as fragments until an opaque black splotch is superposed to allow amodal completion of B's. She did not see color (blue) in the fragments until the splotch was added. But when we retested her a year later she had no recollection of the display, yet saw blue fragments - as if an unconscious memory of the "completed" B's remained in her brain. Results clearly demonstrate that graphemes can cross-activate colors long before they reach consciousness. ("blindsight") This is consistent with the cross-activation occurring in the fusiform gyrus between graphemes (or even PORTIONS of them!) and colors, before being relayed to higher areas for consciousness. Lastly, we showed that the evoked colors behave like "real" non-synesthetic sensory colors; they are blocked by outlines in the same way that neon spreading is.

Binocular vision: Binocular rivalry and awareness

Sunday, May 8, 2:45 - 6:30 pm

Royal Palm 6-8, Poster Boards 318 - 328

36.318 Suppressed images selectively affect perceptual dominance in binocular rivalry

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During binocular rivalry, perception alternates between dissimilar images presented dichoptically. It has traditionally been argued, that the percept during the dominance phase of rivalry is equivalent to that during non-rivalrous monocular viewing. Recent evidence [Pearson, J., & Clifford, C. W. (2005). Suppressed patterns alter vision during binocular rivalry. *Current Biology*, 15, 2142-2148], however, suggests that the suppressed image can affect perception of the dominant one, yet the extent and nature of this interaction remain elusive. Here we seek to understand the mechanism by which suppressed and dominant images interact.

In two experiments, using the same observers, we measured the influence of a mask on discrimination performance for small probes. The probe and masks were presented to either the same eye (monocular: both dominant) or to different eyes (dichoptic: probe dominant, mask suppressed). In the first experiment, both probe and masks consisted of sine-wave gratings. The task was to indicate whether the probe was oriented clockwise or counter-clockwise from vertical. The second experiment was similar, but instead of orientation we measured the effect of motion masks in a (left-right) motion discrimination task. All motion stimuli consisted of moving pixel noise.

Our results show that performance on orientation discrimination and motion discrimination is affected by the nature of, and the difference in feature space (orientation or motion) between masks and probes. Interestingly, the selective interference of the mask was qualitatively similar for the monocular and the dichoptic condition. This means that perception of dominant images is affected by suppressed images as if the images were actually visible, when in fact they were not.

36.319 Fast unconscious fear conditioning

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How do conscious and unconscious visual processing differ? Suppressing visual stimuli from awareness has previously revealed quantitative differences, either reducing or eradicating their processing. Finding qualitative differences, however, would further benefit the understanding of systems mediating conscious versus unconscious processing. Here, we show such a difference in the timing of conscious and unconscious fear acquisition, an essential function for adaptive behavior. Threatening stimuli can be detected, and the fear they elicit physiologically expressed, outside awareness; but whether new fear can be learned for stimuli suppressed from awareness is unknown.

We used Pavlovian fear conditioning, suppressing long-duration conditioned stimuli (CSs) from awareness with continuous flash suppression (CFS). During CFS, stimuli presented to one eye are rendered invisible by salient dynamic stimulation of the other eye. One suppressed stimulus (CS+) was occasionally paired with a shock, whereas the other (CS-) was not. Importantly, the temporal parameters of CFS enabled measurement of participants' skin conductance responses (SCRs) during acquisition, so the development of learning could be tracked over time. Two participant groups were conditioned with identical CSs, either with CFS (unaware group) or without it (aware group).

We found significantly greater SCRs to the CS+ in both groups, but the temporal pattern of learning differed. Robust learning was observed only during early acquisition (1st half of the 36-trial session) for unaware participants, and only during late acquisition (2nd half) for aware participants. Conditioning magnitude was negatively correlated with state anxiety in both groups, but only during the stage in which differential learning occurred.

Conscious fear acquisition developed gradually, whereas unconscious fear conditioning was rapid but habituated swiftly. Unconscious learning may therefore involve automatic orienting to threats, probably mediated by amygdala activity (known to habituate quickly); conscious conditioning may employ higher-level cognitive mechanisms (perhaps involving cortical structures) allowing associations to form over time.

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36.320 Breaking continuous flash suppression: A measure of unconscious processing during interocular suppression?

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For decades, psychologists have sought to determine the degree to which invisible stimuli are processed without conscious awareness. Recently, a promising new approach has been introduced for examining preserved high-level processing of perceptually suppressed stimuli. This approach makes use of continuous flash suppression (CFS), a variant of binocular rivalry to render stimuli presented to one eye invisible. Unconscious processing is inferred from the time that initially invisible stimuli need to overcome such interocular suppression and become visible. This breaking CFS paradigm has received increasing popularity, and many studies have interpreted shorter suppression durations for familiar, meaningful or emotional stimuli as evidence for enhanced unconscious processing of such stimuli. In the present study, we asked if the breaking CFS paradigm indeed reflects unconscious stimulus processing or if other factors such as lower detection thresholds or criteria can account for reduced suppression durations. In a series of six experiments we compared the time it took upright and inverted faces to become visible during CFS and in perceptually similar control conditions not involving interocular suppression. We found that not only during CFS, but also in appropriate control conditions upright faces were detected faster and more accurately than inverted faces. The breaking CFS paradigm may thus simply reflect different thresholds or criteria for visual stimulus detection, rather than unconscious processing. We conclude that, unless proven otherwise, the breaking CFS paradigm is not capable of providing unequivocal evidence for unconscious visual processing. Instead, we propose an alternative approach for measuring the processing of high-level stimulus attributes during interocular suppression. We developed an indirect probe detection method that circumvents the influence of detection thresholds and criteria and hence provides an accurate and unbiased estimate of suppression durations during CFS.

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36.321 Binocular depth modulates high-level visual perception without awareness

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Binocular depth does not always break through top-down suppression to consciousness when the stimuli have intrinsic depth property. For example, the back of a hollow mask is consistently interpreted as a normal face by healthy people (Dima et al., 2009; Schneider et al., 1996); and depth-scrambled point-light walkers are perceptually regulated into normal walkers through stereoscopic vision (Bülthoff et al., 1998). Do these seemingly uncompetitive and subliminal binocular depth cues have any functional role in high-level visual perception? Using 3D point-light walkers presented with stereoscopic glasses, we identified a subgroup of participants (20%) who incorrectly interpreted all the rear-view (facing away from the viewer) 3D walkers as facing toward themselves. Despite that they couldn't discern between the 3D walkers with opposite facing directions in a forced-choice task, they had no difficulty in identifying moving direction of non-biological 3D objects. Most crucially, these participants were more sensitive in discriminating the walking direction of the walkers (left vs. right) that were facing toward than away from them, similar to the response pattern observed from the participants who accurately perceived the 3D walkers in depth. Our results demonstrate that binocular depth information could be sometimes registered independent of depth perception and modulate high-level visual perception.

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36.322 Interocular conflict attenuates change-blindness

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During binocular rivalry, perception alternates between dissimilar images presented dichoptically. It has been argued that the interocular conflict between the images leads to competition: the images compete to become the dominant percept. In the present study we ask a simple question: how salient is interocular conflict? We used a change-blindness paradigm in which observers had to detect a change in a display that was turned on and off continuously. The displays consisted of natural scenes in which a change occurred in a small region of the image. The change occurred either in one eye (monocular) or in both eyes (binocular). Additionally, observers had to detect changes in displays in which the change consisted of the combination of the changed and unchanged part of the image (transparent). Observers were instructed to press a button as soon as they had located the change. To check for accuracy, they also indicated the nature of the change. The results show that reaction times for correctly locating the change were much shorter for monocular than for binocular or transparent changes. This finding implies that monocular changes are more salient than binocular changes, although binocular changes are presented to both eyes. Clearly, the visual system is set to quickly detect the competition evoked by interocular conflict.

36.324 Fluctuations of visual awareness: Motion induced blindness and binocular rivalry

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Motion-induced blindness (MIB) and binocular rivalry (BR) are popular paradigms to study visual awareness. It has been suggested that both phenomena are related and share a common oscillator (Carter & Pettigrew, 2003). In two experiments we tried to determine whether BR affects MIB by creating an experimental paradigm that can elicit both. In the first experiment eighteen observers fixated the center of a display with a moving mask and a superimposed stationary target in a split-screen Wheatstone configuration for 30 sec. Each observer reported disappearance and reappearance of a salient target dot in the upper visual field by pressing and releasing a labeled key. The mask was a rotating grid of crosses or a drifting sine-wave grating. In a within-subjects design the mask was presented in rivalry or not; with opposite rotation and orthogonal drift in the left and right eye or with the same rotation and drift in both eyes. In addition, the target was presented to both eyes (binocular target) or to one eye only (dichoptic target). Results show that MIB as measured by normalized disappearance was significantly increased for dichoptic targets but remained unaffected by binocular rivalry in the different masks. Independence of MIB from BR was confirmed in a second experiment in which isoluminant red and green target dots were presented to the left or right eye and observers reported perceived color as a measure of binocular rivalry in addition to target disappearance. In conclusion, our preliminary results suggest that MIB is independent of BR. Further analyses on the dynamics of target perception will inform whether or not the two phenomena fluctuate independently of each other.

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36.325 Manipulating contrast of multistable stimuli dissociates selection and maintenance of perceptual dominance in binocular rivalry

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In binocular rivalry, conflicting visual inputs result in perceptual alternations of the two inputs. Levelt (1968) demonstrated that increasing the contrast of one eye's stimulus does not affect the mean duration of perceptual dominance of that stimulus, but instead decreases the mean duration of perceptual dominance of the stimulus presented to the unmanipulated eye. Stimuli introduced by Diaz-Caneja (1928) have been used to study perceptual selection at different levels of the visual processing hierarchy. Specifically, a horseshoe-shaped stimulus facing either left or right is presented to one eye, and a horseshoe stimulus facing in the opposite direction is presented to the other eye. These stimuli result in four distinct percepts: left-

facing horseshoe, right-facing horseshoe, concentric circles, and horizontal lines. The horseshoe percepts correspond to the monocular images, while perception of horizontal lines or concentric circles requires integration of information from both eyes and therefore reflects perceptual dominance of binocular stimulus representations. In this study, we manipulated the contrast of either the monocular horseshoe stimuli or the portions of each stimulus that group to form percepts of concentric circles or horizontal lines. Our results show that for Diaz-Caneja stimuli, increasing the contrast of a stimulus increases the mean perceptual dominance duration of that stimulus, in contrast with the classic Levelt finding. In addition, increasing the contrast of a monocular stimulus increases the probability of perceptual selection of that stimulus, but increasing the contrast of portions of the stimuli that form an interocularly grouped percept does not change the probability of perceptual selection of that percept. These results suggest that selection processes in binocular rivalry are distinct from those that underlie the maintenance of perceptual dominance and that the strength of inhibition from the suppressed eye is not the only determinant of perceptual dominance maintenance.

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36.326 Attention controlled binocular suppression in non-amblyopic population

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It is known that some amblyopes can focus their attention to the input from one eye and suppress that from the other eye at will. We explored whether a person with no amblyopia history can have such ocular based attention. Four observers with no known history of amblyopia participated in the experiment. The stimuli in each trial contained a Gabor target in one of the four possible locations (up, down, left and right) that presented to one eye and a Gabor distractor at another location either to the same or to the other eye. Other possible locations for stimulus presentation in both the left and the right eye images were filled with white noise. A cue at the center of the display indicated the location of the target. The cue was presented to only one eye to control the ocular attention of the observers. In addition, a fixation point which carried no information about target location was presented to the uncued eye. The task of the observer was to determine which one of the two locations indicated by the cue contained the target. Thus, to perform the task, the observer had to attend to the cued eye. We measured the detection threshold at 75% accuracy. The target threshold in uncued eye increased more than 3.5-fold (11.2dB) from that in the cued eye for the dominant eye and about 3-fold (9.3dB) for the non-dominant eye. Such suppression of the unattended eye suggests that binocular suppression can be voluntarily controlled. Hence, it is possible to build an amblyopic model among normal population.

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36.327 Semantic analysis does not occur during interocular suppression in the absence of awareness

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It has been intensely debated whether visual stimuli are processed to the point of semantic analysis in the absence of awareness. In the present study, we used two related interocular suppression paradigms to measure the extent to which the meaning of a stimulus was registered across multiple levels of visibility. To infer whether a stimulus was semantically analyzed we measured the N400 component of observers' event-related potentials (ERPs), a highly sensitive index of the semantic mismatch between a stimulus and the context in which it is presented. Observers judged the semantic relatedness of a prime and target word while ERPs were recorded under continuous flash suppression (Experiment 1) and binocular rivalry (Experiment 2). Also, we parametrically manipulated the visibility of the target word by increasing the contrast between the target word and the suppressive stimulus presented to the other eye (Experiment 3). We found that the amplitude of the N400 was attenuated with increasing suppression depth and absent whenever the observers could not discriminate the meaning of the words. We interpret these findings in the context of single-process models of consciousness which can account for a large body of empirical evidence obtained from visual masking, attention and, now, interocular suppression paradigms.

36.328 Linguistic Penetration of Suppressed Visual Representations

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Linguistic labels (e.g. "chair") appear to activate associated visual properties of the objects to which they refer (Lupyan 2008, Lupyan & Thompson-Schill, 2010). Labels can also inform visual tasks and offer performance advantages compared to nonverbal cues. Can hearing verbal labels make visible images that are otherwise invisible? In two experiments, we used anaglyph glasses and continuous flash suppression (CFS) to suppress images of objects from awareness. CFS involves presenting dynamic, high-contrast patterns to one eye and an object to the other eye and produces continuous suppression of the object. For each trial, participants heard either 1) a label corresponding to the suppressed object, 2) a label corresponding to a different object, or 3) white noise. Participants then viewed the pattern-object anaglyph and performed a simple detection task. If they detected any object, they were asked to verify its identity. We predicted that if labels activate visual information, hearing a label should "un-suppress" the object, but only if the label corresponds to the object.

Hearing a valid label prior to the object-detection task resulted in a significant increase in hit rate for simply detecting object presence, relative to baseline (an uninformative cue). Invalid labels resulted in a nonsignificant decrease relative to baseline. Signal-detection analysis showed a reliable increase in d' following valid labels relative to baseline. We observed a similar pattern for verification responses. Analysis of correct-detection reaction times (RTs) revealed significantly shorter RTs following valid cues compared to invalid cues, and marginally longer RTs following invalid cues relative to baseline. A replication of the experiment using lower-contrast images to make detection more difficult yielded similar benefits of valid labels in both accuracy and RTs.

Labels may preactivate visual properties associated with the labeled object in a top-down fashion. This top-down linguistic assistance propels the image into awareness.

Perception and action: Navigation and wayfinding

Sunday, May 8, 2:45 - 6:30 pm

Orchid Ballroom, Poster Boards 401 - 412

36.401 Estimating motion parallax during fixational head movements

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During visual fixation, unless the head is artificially constrained, involuntary, small head movements significantly contribute to the motion of the retinal image (Skavenski et al., 1979). In this study, we investigated whether the resulting retinal image motion provides useful depth information in the form of motion parallax. Head movements in human observers were measured by means of a custom-developed high-resolution method, which uses a Phasespace motion capture system with 4 cameras (480 Hz) and a tightly-fitting helmet with 20 active optical markers. Preliminary measurements with the helmet mounted on a robotic manikin head have shown this method gives resolution higher than 2' for head rotations and better than 1 mm for head translations. Recordings were made while subjects maintained prolonged steady fixation on targets located at distances of 0.5-3 m, while standing or sitting with their head unrestrained. The mean translation and rotation velocities measured in the experiments were 3.6 mm/s and 25' /s, respectively. Physical modeling of the head and eye enabled estimation of retinal image motion. Significant retinal image motion was found even under the assumption that eye movements perfectly compensated for head movements, so to yield complete stabilization of the fixated target. For example, during fixation on an object at 130 cm, retinal speeds larger than 1' /s were already found for objects located just 10 cm away from the fixation point. The speed of the retinal image increased monotonically with the distance of the object from the fixation point yielding velocities well above thresholds. Furthermore, retinal velocities increased even more if perfect stabilization of the fixated target was not assumed, as it is known to

occur from previous studies. These results show that retinal image velocities caused by fixational head movements are within detectable levels for the visual system and may contribute to depth perception.

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36.402 Successful detection of a size change during self-movement

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A change in radius of a stationary object is signalled to a stationary observer by a change in retinal size. Such a change is readily detected. If the object is approaching the observer then detection is more difficult - change in retinal size is no longer sufficient. The observer needs to pick up a change in the relationship between the monocular and binocular cues to motion-in-depth. If the observer is moving and the object is embedded in a stationary scene then an additional solution is available. It has recently been proposed (eg Rushton & Warren, 2005, *Current Biology*; Warren & Rushton, 2009, *Current Biology*) that during self-movement the brain uses its sensitivity to optic flow to identify and subtract out components of global retinal motion that are due to self-movement ("flow parsing"). This isolates components of retinal motion that are due to movement of objects relative to the scene. If the brain performs flow parsing, detection of a change in object radius should be easier when the observer approaches the object rather than when the object approaches the observer. Across a series of experiments we explored this prediction. Observers viewed a scene consisting of 25 wire-frame objects arranged in a volume of 60cm depth, centred 90cm away. In the first experiment a central sphere moved towards the observer. Observers had to indicate whether or not the approaching object was changing size. On 50% of the trials the sphere changed in radius during approach, on the other 50% it did not. Performance (group average, N=5) was barely above chance. In a second experiment the central sphere moved (and changed radius) in the same way but now the whole scene approached the observer. Performance was above 90% correct. We conclude that observers can detect a change in size during self-movement and that performance is compatible with the involvement of a flow-parsing process.

36.403 Investigating the role of single-viewpoint depth data in visually-guided mobility

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Background: Depth information is critical for navigation, and may be recovered visually via multiple cues. However, some cues may only be accessed by deliberate action (e.g., parallax and visual motion) rather than from a single viewpoint (e.g., disparity). At low visual resolution with sparse representation (35x30 pixels over 100 degrees), cues such as disparity are limited. Current retinal implants for the visually impaired are around or below this resolution. We investigated the importance of depth being available from a single viewpoint for navigation. An experiment was designed to compare a depth representation to intensity (the standard representation for retinal implants) for visual navigation. In Depth, brightness represents environment depth of the corresponding visual field. In Intensity, brightness represents luminance. Methods: Four normally-sighted participants navigated an indoor mobility course comprising white walls, dark floor, and contrasting obstacles over multiple trials. Participants wore head-mounted stereo cameras to collect visual information. This was processed to create phosphorized depth or intensity representations and presented via a head mounted display. Course traversals were measured as percentage of preferred walking speed (PWS), against a baseline traversal with high-resolution images. Results: Both depth- and intensity-based representations were effective for visually-guided navigation: participants walked significantly faster than 40% of their PWS, walking speed was significantly faster with Intensity than Depth. Presence of obstacles had a differential effect on depth- and intensity-based navigation. When suspended obstacles were present, participants walked significantly slower with Intensity, while no significant difference was evident for Depth, compared to performances in the no-obstacle environment: this difference was significant. Conclusions: These results demonstrate that humans can navigate using a purely

depth-based representation of the environment, and suggest that it may be advantageous to have access to depth from a single viewpoint in some situations.

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36.404 Mobile Robot vision navigation and obstacle avoidance based on gist and saliency algorithms

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Two of the important capabilities needed for scene understanding are extracting the gist of the scene and identifying salient regions in the image. Here we present a robotic vision system that utilizes these two modules to understand its surrounding from an image. That is, we would like the robot to be able to localize and navigate in its environment. We present a vision-based navigation and localization system using the two biologically-inspired scene understanding models. For localization, gist, which captures the holistic characteristics and layout of an image, coarsely localize the robot to within the general vicinity. Then, saliency, which emulates the visual attention of primates, refine the location information by recognizing the detected conspicuous regions in the image.

For the vision navigation sub-system, we use the gist features to identify the road region. Here, the image is segmented into multiple regions, which are then classified using the gist features to find most likely road region. By incorporating knowledge about the road geometry, the system is able to locate the center of the road as well as avoid obstacles. At the same time, we also use the recognized salient regions to prime the location of the road in the image. Furthermore these regions provides high level navigation parameters such as distance to the junction and overall heading of the road (Chang et al., 2010). The navigation system then uses the estimated road parameters to perform visual feedback control to direct the robot's heading and to go to a user-provided goal location.

We test the vision localization and navigation system at four sites (one indoor and three outdoor environments) using our mobile robot, Beobot 2.0. The system is able to keep robot in the center of the lane with a route length over 138.27m.

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36.405 Spatial Navigation: Why is Active Exploration Better than Passive Exploration?

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It seems that actively walking around a new city leads to better spatial knowledge than passively riding in a taxi, yet the literature is decidedly mixed. "Active" exploration has several components that are often conflated. We test four contributions to spatial learning: (1) visual information, (2) vestibular information, (3) motor/proprioceptive information, and (4) cognitive decision-making. Participants learn the locations of 8 objects in an ambulatory virtual maze environment, and are tested on their survey or graph knowledge. Six learning conditions are crossed with two test conditions, yielding 12 groups: (a) Free Walking: participants freely explore the environment for 10 minutes, providing all active components. (b) Guided Walking: participants are guided along the same paths, removing decision-making. (c) Free Wheelchair: participants in a wheelchair press buttons to steer through the maze, minimizing motor/proprioceptive information. (d) Guided Wheelchair: participants are wheeled through the maze along paths that match the Free Walking condition, providing visual and vestibular information. (e) Free Video: participants press buttons to steer through a desktop VR maze, providing visual information and decision-making. (f) Guided Video: participants watch a participant's-eye video of the Free Walking condition, providing only visual information. In the test phase, participants are wheeled to object A and instructed to walk to the remembered location of object B: (i) Survey task: the maze disappears and participants take a direct shortcut from A to B. (ii) Graph task: participants walk from A to B within the maze corridors, with detours. In the survey task, shortcuts tend to be more precise when participants walk during exploration, indicating that motor/proprioception is critical for active learning. In the graph task, decision-making also aids learning, but only in conjunction with motor-proprioceptive information. These results suggest that desktop VR may be insufficient for full spatial learning.

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36.407 Is Path Integration an Automatic Process or a Back-up System for Landmark-based Navigation?

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Human and animals are able to navigate to a previously visited place based on visual landmarks or path integration, a process that keeps track of location and orientation during self-motion. Path integration is often assumed to function automatically, continuously running in the background (e.g., May & Klatzky, 2000), whereas other studies have shown that it is overshadowed by salient visual landmarks and may serve as a back-up system when landmarks fail (e.g., Foo et al., 2005; Zhao & Warren, Psychonomics 2010). We tested whether path integration in navigation with visual landmarks is a continuous process or is a back-up system modulated by landmark reliability. Participants performed a triangle completion task in an open virtual environment. Three set of trials were tested sequentially: landmark trials (landmarks were always present); catch trials (landmarks disappeared at response in 10% of trials), and path integration trials (no landmarks). If path integration is continuously running in the background, performance in catch trials should be equivalent to that in path integration trials. However if it is modulated by landmark stability, performance in catch trials should be worse than in path integration trials. Participants showed significantly greater constant and variable errors in catch trials than in path integration trials ($p < .05$), suggesting that path integration is "dialed down" in the presence of stable landmarks. This effect was primarily due to the first catch trial ($p < .01$), while the rest showed no difference from path integration trials, indicating that path integration is quickly "dialed up" when landmarks fail. These results are consistent with the idea that human navigation is dominated by salient visual landmarks, while path integration serves as a back-up system rather than running automatically and continuously.

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36.408 Visual estimation of travel distance by leaky integration along veering paths

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When humans use vision to gauge the travel distance of an extended forward movement they often underestimate the movement's extent. This underestimation can be explained by leaky path integration, a process by which the movement is perceptually integrated to yield distance. Distance underestimation occurs because this integration is imperfect and contains a leak that increases with distance traveled. However, the leak might accumulate with walked distance or might accumulate according to represented distance from the starting point. For movements along a straight line these two possibilities cannot be distinguished, but for movements along a curvy path the distance traveled along the path and the distance accumulated from the origin become separated. We simulated movement along a path veering left and right off a straight line connecting the origin to the end of the movement. We asked observers to indicate the distance between origin and end point of the movement. By varying the amplitude of the veering we created differences between the distance of the movement and the length of the path that was traversed. We then measured the influence of the path length on the distance judgment. Leaky integration along the path makes the seemingly counterintuitive prediction that the estimated origin-to-end point distance should decrease with increasing veering, because the length of the path over which the integration occurs increases, leading to a larger leak effect. Thus, a single origin-to-end-point distance should yield progressively shorter distance estimates as the path length increases. The results matched the prediction: movements of identical origin-to-end point distance were judged as shorter when the path became longer. We conclude that leaky path integration for visual travel distance estimation takes place along the actually traversed path even when a straight beeline distance is calculated.

36.409 An examination of navigational differences between good and poor navigators.

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Everyday experience suggests that certain people can easily find their way back to a starting point along a route they have only experienced once, while others have considerable difficulty. The focus of this research is to

gain a greater understanding of why good and poor navigators differ in their wayfinding abilities. This study was conducted to gain a broad idea of various factors that may influence navigational performance. Participants were guided through a building and then asked to find their way to a destination. In order to examine navigational strategies used by good and poor navigators, participants were asked to think aloud as they found their way to a target location. The verbal statements indicate that good navigators appear to plan routes and observe spatial relationships between landmarks more frequently than poor navigators. Participants also completed a series of questionnaires to assess their ability to (1) recognize landmarks, (2) remember directional information, (3) determine spatial relationships between landmarks and (4) form cognitive maps of environments. Good navigators outperform poor wayfinders on most of these tasks. A discriminant analysis of these findings suggest that the ability to form spatial relationships between landmarks is an accurate predictor of overall spatial ability. Future studies will aim to examine these navigational abilities in further detail using virtual reality.

36.410 Judging the approach speed of motorcycles and cars in night-time driving conditions

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The ability to accurately judge the approach speed of a motorcycle is critical in order to avoid right of way violation accidents at junctions. Research has demonstrated that individuals consistently judge the time to contact (ttc) of a motorcycle to be later than that of a car (Horswill, Helman, Ardiles & Wann, 2005). However, the majority of studies surrounding the judgement of motorcycle speed have taken place in daylight hours and very little is known about how individuals make these judgements in night-time conditions; where the perceptual information available is severely reduced. We measured the accuracy of adult drivers' speed judgements for motorcycles and cars in night-time conditions. Solid white headlights were presented on a black background in a virtual environment and arranged to represent a motorcycle or car headlight formation, both with the same headlight diameter. These stimuli were presented either simultaneously or sequentially with a fixed ttc of 4 seconds at their closest position (sufficient time to pull out of a junction). Participants were asked to make a 2FC judgement as to which vehicle was travelling the fastest and thresholds for speed differences were estimated using an adaptive (best-PEST) psychophysical procedure. Results demonstrated that individuals were significantly more accurate when judging the speed of the car compared to motorcycle, which suggests that they are using the separation of the headlight stimuli to make judgements rather than the looming of the headlight contours. The difference between car and motorcycle stimuli can then be offset to some degree by re-arranging the motorcycle lighting configuration. The results indicate that people misjudge the approach speed of motorcycles in night-time conditions; thus increasing the likelihood of a driver pulling out in front of them and causing an accident. Engineering modifications that could reduce this risk are currently being investigated. Research supported by the UK EPSRC and UK ESRC

Acknowledgement: UK EPSRC and UK ESRC

36.411 Task-dependent gaze priorities in driving

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During complex visuo-motor tasks, gaze behavior is largely controlled by the current task [1]. However, it is unclear how gaze allocation is accomplished when confronted with multiple task demands, especially in dynamic and unpredictable environments, as in driving. This has been called the "scheduling problem". One simple solution is to actively search the visual scene for potentially important information (e.g. pedestrians, other cars, lane centering) at regular intervals (round-robin strategy). Another is to weight search frequency by the importance of the sub-tasks, as in reward-based models of gaze allocation. Alternatively, participants might rely on attentional capture by salient events. To address this question, we manipulated the tasks demands of participants who drove in a virtual environment including other cars, pedestrians and urban scenery. While driving there are several concurrent sub-goals, including avoiding other cars, following a lead car, and avoiding pedestrians. We recorded and analyzed gaze behavior for these driving sequences. These data provide the ground truth for

gaze allocation as well as unique traversals through the environment for use in simulations. We simulate gaze allocation as a high-level, object based scheduling problem where covert object searches are engaged at regular intervals. If the object is present onscreen, an overt fixation occurs. Simulations were run with a uniform distribution across object categories and using a round-robin strategy. We found neither to be a good predictor of gaze allocation. Weighting search frequency by participants' global fixation distributions provides a better fit and using fixation distributions for local scene context provides the best. If subjects' fixation distributions are proportional to task priority, we discuss how a task-based reinforcement-learning model may accomplish such gaze allocation. [1]Hayhoe M. & Ballard, D. (2005) Eye movements in natural behavior. *Trends in Cognitive Sciences*, 9(4), 188-193.

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36.412 The role of decision-making in learning spatial layout: A real-world application

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Making decisions about how to navigate through an environment promotes better learning of the layout than does passive exploration (e.g., Bakdash, 2010). We sought to apply this finding to a real-world problem in which decision-making is limited: Infantrymen in the U.S. Army often have trouble learning the layout of a destination because they are transported in vehicles without windows. Equipping these vehicles with cameras will provide infantrymen with a view of the outside environment, which will certainly improve spatial knowledge. However, giving infantrymen control of a camera view may improve spatial knowledge further by letting them decide where to look during navigation. On a computer desktop, participants viewed an outdoor virtual environment from the inside of a simulated enclosed stationary vehicle. They were instructed to learn the details of the environment by rotating the camera and moving it up and down. Participants were tested in pairs, one of whom had active control of the camera and made decisions about where to look, while the other passively watched the output generated by the first participant. After 3 minutes, participants' spatial knowledge was assessed via their ability to recognize targets, point to target locations, and create a map of relative target locations. In an effort to match the circumstances of this problem, participants were not given prior information about the targets and were given a limited amount of time to explore the environment. This contrasts with previous laboratory-controlled studies, in which participants had prior knowledge of the targets and extensive time to explore. Having camera control improved target recognition, but contrary to our hypothesis, control did not improve target localization or map construction. These results highlight the difficulties and importance of applying scientific findings to more complicated real-world scenarios.

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Perception and action: Neural Mechanisms

Sunday, May 8, 2:45 - 6:30 pm

Orchid Ballroom, Poster Boards 413 - 421

36.413 The visual P2 is attenuated for objects near the hands

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Recent findings have shown that vision is altered when you place your hands near the object you are looking at (Abrams, Davoli, Du, Knapp, & Paull, 2008; Davoli & Abrams, 2009). It is, however, not known at what stage of visual processing the presence of hands in the visual field begin to have an effect on perceptual and attentional functioning. To determine the underlying neural processes of this effect, the present study examined electrophysiological measures of brain activity. We measured visual evoked potentials (VEPs) while participants either had their hands in their visual field (hands up condition) or lowered (hands down condition). Participants indicated whether a cross at fixation changed colour while passively viewing a black and white checkerboard reversal pattern (1.5 Hz). Time locked VEPs to checkerboard reversals revealed that when the hands were near the display, an attenuation of the attention-related P2 component was

observed for centrally presented stimuli but not for peripherally presented stimuli. These results provide support for the view that spatial processing is enhanced for hand-near objects.

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36.414 Visually-evoked readiness potentials reflect anticipation and/or preparation of future movements rather than acts of will

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Libet's study of the readiness potential (RP; Libet et al. 1983)—an event-related potential (ERP) that precedes endogenously-willed actions—has called into question the ability of our conscious will to cause behavior. Since the RP begins well before subjects report willing a movement, some have concluded that conscious volition is illusory—a report to our conscious mind of decisions that our unconscious brain has already made (see Libet 1993). An associated ERP known as the lateralized readiness potential (LRP) also precedes reports of conscious decisions to act and provides further ammunition for this position. In this study we performed two experiments. First, we replicated Libet's method and additionally compared the reported time of conscious willing of movements to corresponding onsets of the RP and LRP. We found no covariation between this reported time and either the RP or LRP onset, suggesting that the RP and LRP may underlie processes independent from volition. Second, we recorded RP-like ERPs in subjects as they readied an exogenously-cued movement, suggesting that the RP may reflect processes of anticipation or preparation rather than volition. This conclusion is supported by a previous report (Matsushashi & Hallett 2008) that thoughts of movement begin well before reports of conscious will, and if true would leave open the possibility that conscious volition can cause behavior.

36.415 Motor cortical and distributed network modulation during visuo-motor learning: a TMS-EEG study

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Prior studies have shown changes in motor cortical outputs associated with implicit and explicit motor learning. This study aims to evaluate changes in local cortical reactivity and distributed neural network dynamics in the course of motor sequence learning. We record electroencephalographic (EEG) responses to single-pulse transcranial magnetic stimulation (TMS) at baseline and serially while participants perform 4 blocks of a serial reaction time task (SRTT). On each trial, upon the appearance of a visual cue at one of four possible positions, participants have to press an appropriate key. Random trials are compared with trials repeating a sequence of 12 items. TMS is applied over M1 in the time window between motor response and onset of the following visual cue. TMS is also applied between SRTT blocks. Motor-evoked potentials (MEPs) of the first dorsal interosseous are recorded. Decrease of reaction times for sequence trials, compared to random trials, is indicative of sequence learning. During practice, explicit knowledge of the sequence might develop. This can be reflected by changes in responses to TMS, specific to the learning state, during the task performance and during following periods of rest. Preliminary results shows that MEPs recorded after each block, compared to baseline MEPs, reflect changes in cortical reactivity associated with learning. Moreover, playing a sequence of random trials, compared to rest, modifies local reactivity. Finally, responding to a sequence that is getting familiar, compared to performing random trials, also modifies brain responses in remote areas. Distinct phases of learning are associated with different changes in local motor cortical reactivity and distributed neural network modulation. These preliminary data highlight the importance of capturing brain local and distributed network activity in order to fully understand the neural substrates of visuo-motor learning. This is possible with the integration of TMS and EEG during SRTT.

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36.416 The Flickering Wheel Illusion: when alpha rhythms make a static wheel flicker

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Even though neuronal oscillations pervade the brain, our sensory perception of the world does not appear to oscillate: the brain must have developed strategies to conceal the consequences of these oscillations from our perception. Could these concealment strategies be fooled by suitable stimuli, so that our brain rhythms would be revealed to us? Here we report on a novel illusion in which the center of a static wheel stimulus, made up of 30 to 40 alternating black and white spoke sectors, is experienced as flickering. The flicker occurs most strongly during small eye movements performed with the stimulus in the visual periphery (indeed, the illusion was first discovered accidentally while reading text just above a similar-looking wheel). However, we show that stimulus motion relative to the retina is not crucial to perceive the illusory flicker: comparable amounts of flicker are also experienced on the afterimage of a wheel, produced after a few seconds' exposure to the stimulus pattern followed by instant removal -yet by definition this afterimage is stationary on the retina. To address the neuronal basis of the illusion, we recorded EEG while observers (N=20) performed smooth pursuit eye movements, following with their gaze a slowly rotating dot around a wheel pattern; all the while they reported the occurrence of perceived flicker using a button press. The illusion was maximal for certain eye positions around the wheel, and decreased for others. The only frequency band of the EEG that displayed a compatible time course was the alpha rhythm (8-14Hz) recorded over occipital electrodes: when alpha amplitude was strong, the probability of reporting flicker increased. We propose that this new flickering illusion is a unique way to experience the alpha rhythms that constantly occur in the brain, but normally remain unnoticed.

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36.417 Spatial perception deficits in optic ataxia patients

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Damage to the posterior parietal cortex (PPC) is believed to cause deficits in motor actions but not perception. Here we challenge this view by showing that patients with PPC damage also display deficits in perceiving the absolute and relative positions of objects in space. We tested two patients with PPC damage, one with left unilateral optic ataxia (OA) and one with bilateral OA, and 5 neurologically intact controls in 4 paradigms. Subjects were to judge whether a 2nd vertical bar (presented horizontally, randomly -9deg - 9deg, 1deg intervals) was left or right of a memorized initial vertical bar (presented 2deg left, 0deg or 2deg right). They did so in 4 paradigms, 1) while fixating throughout the trial on a cross either 12deg left or right of centre - memory no frame, 2) while switching fixation from one side to the other between the presentation of the two bars - updating no frame, 3-4) same as 1-2 but with the presence of a large frame centered on the screen (20deg*16deg) - memory / updating frame. OA subjects showed greater variability in the perceptual judgment than controls (bilateral OA being the most variable). In addition, both patients showed deficits in perceiving/remembering the locations of bars presented in their contralesional visual fields in all paradigms, resulting in a perceptual shift. The presence of the frame shifted the remembered location of the bar in opposite directions for the two patients, not affecting controls. While perceptual updating was unimpaired in unilateral OA, the bilateral OA patient was unable to update at all. Our results show that damage to the PPC results in perceptual deficits in addition to movement impairments. This suggests that some of the reach related deficits in OA may in part be due to difficulty in correctly perceiving object locations.

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36.418 The Allocentric Brain in Action

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The current study investigated which brain areas are involved in allocentric (scene-based) as compared to egocentric (viewer-based) coding for visually guided hand movements. Using an fMRI block-design, we scanned the brains of 14 subjects while they performed hand movements in either egocentric or allocentric tasks. Using a whole brain analysis we found that performance in both tasks elicited reliable BOLD signals in a sensorimotor network encompassing occipito-temporal, parietal and frontal cortices and the cerebellum. Contrasting BOLD between egocentric and allocentric tasks revealed that the allocentric task led to an increase in BOLD signals in portions of the sensorimotor network, in particular the fundus of the left intraparietal sulcus (IPS), posterior right IPS and bilateral dorsal premotor cortex (PMd). The comparison also showed that the allocentric task led to an increase in BOLD in ventral visual stream areas in lateral occipital cortex (LO) and the fusiform gyrus (FFG) that were separate from the sensorimotor network. We did not find activity specific for the egocentric task. The finding that ventral-occipital areas were recruited during the allocentric, but not the egocentric task, is consistent with neuropsychological data that link the integrity of these areas to successful performance in allocentric movement tasks. The data therefore suggest that areas LO and FFG are essential for the processing of visual information in a scene-based reference frame during visually guided movements. In contrast, activity in the IPS has been linked to the representation of magnitude and visual-spatial processing, and activity in PMd has been linked to the representation and selection of movement parameters. Thus an increase in activity in those areas during the allocentric task might suggest that, compared to the egocentric task, the allocentric task places a higher load on mechanisms that transform visual information about extent and spatial layout into movement parameters.

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36.419 Active motor learning of audiovisual objects

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Previous work has suggested that active motor learning of unisensory items enhances memory while leading to the involvement of motor systems during subsequent perception and recognition. However, the impact of active motor learning on the subsequent perception and recognition of multisensory associations has not been investigated. This is important because we commonly learn through multiple senses while using physical interaction. Therefore, a behavioral and fMRI study was performed in order to explore the impact of active motor learning on subsequent processing of audiovisual stimuli. These stimuli were twenty novel visual objects, viewed from an egocentric viewpoint, that each produced a unique sound when a specific action was performed on the object. Participants learned audiovisual associations from these stimuli either through self-generated actions on the objects (active learning condition), or by observing an experimenter produce the actions (passive learning condition). Immediately after the learning session, accuracy, reaction time, and BOLD fMRI measures were collected during associative perception and recognition tasks. Actively and passively learned stimuli were presented in unisensory (visual and auditory), correctly paired multisensory (congruent audiovisual), and incorrectly paired multisensory (incongruent audiovisual) forms. Active learning facilitated behavioral measures of audiovisual associative recognition. Premotor, motor, and somatosensory cortex were recruited more during the presentation of actively learned audiovisual associations compared to the presentation of passively learned audiovisual associations. Importantly these differences were modulated by the congruency of the paired associations. Overall, the current study demonstrates that active motor learning modulates subsequent audiovisual associative perception and recognition.

36.420 Getting Stuck in a Rut with Decision-Making

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Humans are expert decision makers, capable of assimilating information rapidly and tailoring behaviour optimally, according to task constraints and context. Thus, individuals can produce an effective response to a visual stimulus in a short time frame. Nevertheless, the mechanisms that evaluate

evidence and reach decisions can sometimes select sub-optimal behaviours, with decision-making appearing to become 'stuck in a rut'. We developed a model of learning that revealed this inertia is a naturally emergent feature of a learning system. To test the model, 30 participants (16 female, 14 male, mean age 26.8 years) completed an aiming task designed using specialised software presented on a digitizing tablet (Toshiba Portege M700-13P). A handheld stylus was used as an input device to move a cursor between two points displayed on a computer screen without hitting an obstacle blocking the route. In 'sequential' conditions, the obstacle was displaced to either to the left or the right of the screen and then incrementally moved 15 times away and then towards the starting positions. In the 'random' condition, the obstacle appeared randomly in one of the 15 positions (twice per session). Post-hoc interviews showed participants were unaware that the obstacle moved from trial-to-trial. In the random condition, participants showed a high bias towards selecting the shortest route between the points. In the sequential conditions, participants showed a bias towards the previous selected route (a phenomenon that can be termed hysteresis) even though this was a sub-optimal route avoided in the random condition. The learning model predicted precisely this qualitative pattern of decision-making and demonstrated that the emergent hysteretic effect evident during sequential conditions does not develop with randomisation of the motor task sequence. These results suggest that an understanding of responses to visual stimuli requires a consideration of the learning mechanisms underpinning skilled behaviours.

36.421 Decisions at a glance: The relative cost of multiple possible actions is represented in conscious perception of spatial layout

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Prior to performing a physical action in the environment, decisions must be made to select one from multiple potential actions and then from multiple ways of performing it. One of the chief factors involved in such decisions is the effort required to perform the action. Noting that effort can be difficult to measure, Rosenbaum, Brach, and Semenov (2010) implemented a two-alternative forced choice action procedure that required participants to choose between a short or long reach across a table to pick up a bucket, with the constraint that the choice would also determine how far they had to carry the bucket. Participants' action choices demonstrated a consistent trade-off between the costs of walking and reaching, indicating that the effort involved in individual components of an action sequence play a combined, predictable role in the choice of how to act. In the current study, we replicated their design with several additions. Of primary interest, participants' perception of one potential carrying distance was assessed on each trial prior to performing the actions. When the distance being estimated was one that they believed to require less combined reaching/walking effort (as indicated by the fact that they would later choose to carry the bucket over that distance instead of the alternative choice), the distance was perceived as shorter, and conversely when the distance being estimated was the one they believed to require more combined effort (i.e. they would later choose to carry the bucket over the alternate distance), the distance being estimated appeared farther. Thus, perception of a single component in an action sequence (distance to be walked) was influenced by a second component as well: the effort required to reach. In this respect, it may be that changes to conscious perception of spatial layout serve in part to guide complex action choices.

Multisensory processing: Visual-auditory interactions

Sunday, May 8, 2:45 - 6:30 pm

Orchid Ballroom, Poster Boards 422 - 435

36.422 Neural and Information Processing Measures of Audiovisual Integration

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This research involves an investigation of the cognitive mechanisms underlying audiovisual integration efficiency in speech perception. Speech recognition is a multimodal process engaging both auditory and visual modalities (McGurk and MacDonald, 1976; Sumby and Pollack, 1954). In a pioneering study, Sumby and Pollack (1954) demonstrated that lip-reading, or

visual speech, plays a crucial role in speech recognition by enhancing accuracy across multiple auditory signal-to-noise ratios. Although traditional accuracy-only models of audiovisual integration, such as the Fuzzy Logical Model of Perception (Massaro, 2004) and Braidá's Pre-Labeling Model (Braidá, 1991), can adequately predict audiovisual recognition scores and integration efficiency (Grant, Walden, and Seitz, 1998), they fail to specify the real-time dynamic mechanisms behind integration. The limitations of traditional modeling approaches thus motivated the use of (non-parametric) statistical and experimental tools in a series of recent studies (Altieri, 2010). Altieri (2010) utilized a reaction time and information processing measure known as "workload capacity" (Townsend and Nozawa, 1995) to quantify integration efficiency/multisensory benefit in speech perception. The capacity measure was used to compare (transformed) reaction time distributions obtained from the audiovisual condition, to the auditory-only and visual-only reaction times in speeded speech discrimination tasks. Three auditory signal-to-noise ratios were employed. The results revealed that efficient audiovisual integration, measured by a workload capacity coefficient greater than 1, was only observed for low auditory signal-to-noise ratios. New experiments using combined ERP and reaction time methods are being implemented to assess how brain signals relate to behavioral and information processing measures, including capacity. Preliminary data analyses indicate increased suppression of the audiovisual ERP waveform relative to the auditory-only ERP signal in frontal and left parietal/temporal regions as the auditory signal-to-noise ratio decreases, and integration efficiency increases. Benefits of combined EEG/reaction time studies include obtaining generalized neural and behavioral measures of integration efficiency for speech and non-speech stimuli.

36.423 Synchronized audio-visual transients drive efficient visual search for motion-in-depth

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In natural audio-visual environments, a change in depth is usually correlated with a change in loudness. In the present study, we investigated whether correlating disparity and loudness provides a functional advantage in binding disparity and sound amplitude in a visual search paradigm. To test this assumption, we used a method similar to that used by Van der Burg et al. (2008) to show that non-spatial modulations of loudness can drastically improve spatial visual search for a correlated luminance modulation. Subsequently (2010), they varied the shape of temporal modulation and demonstrated that transient events (square modulations) are required for this search efficiency, and that sinusoidal audiovisual modulations do not support efficient search. We used dynamic random-dot stereogram displays to produce pure disparity modulations. Target and distractors were 0.35 x 0.35 degrees disparity-defined squares (either 6 or 10 in total) presented on a ring at 2.5 deg eccentricity. Each square moved back and forth in depth from zero to +12 arcmin (crossed) disparity at different phases. The target's depth modulation was synchronized with an amplitude-modulated 500 Hz tone. Visual and auditory modulations were always congruent (both sinewave or squarewave). Four observers were asked to give speeded responses in a discrimination task on the target. Because binocular matching processes are known to favor smooth over abrupt changes of disparity across space and time, we expected the sine modulation condition to be at least as efficient as the square modulation in supporting efficient search. However, results show a significant improvement in visual search in the square condition compared to the sine condition, suggesting that transient auditory information can efficiently drive visual search in the disparity domain. In a second experiment, correlating sound with a distractor led to longer search times, indicating that the correlation is not easily ignored.

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36.424 Modulation of multisensory processing during rapid reaching movements

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Humans appear to make extensive use visual information during rapid upper limb reaches (e.g., Elliott et al., 2010). In an attempt to assess the visual regulation of goal-directed action from a multisensory processing

perspective, we recently employed an audio-visual illusion (e.g., Shams et al., 2000) presented at different times during rapid reaching movements. These previous results demonstrated that susceptibility to the fusion illusion (i.e., perceive one flash when two flashes are presented with one beep) is reduced at high limb velocities (Tremblay & Nguyen, 2010). That is participants were more likely accurately report two flashes in the fusion illusion condition only when their limb traveled at more than 1.5 m/s. However, one missing component of that study was a resting control condition, which we added in the present study. As in the previous study, we always presented either 1 or 2 beeps with 1 or 2 flashes. Our experimental design included one control resting condition, performed at the beginning or the end of the protocol (i.e., counterbalanced across participants). As well, in the main experimental phase, one of the 4 audio-visual conditions was presented at one of 5 times relative to the onset of a rapid reaching movement (0, 50, 100, 150, and 200 ms after movement start). All experimental phase conditions were presented pseudo-randomly, 12 times each. This current study first replicated the influence of limb velocity on the fusion illusion (i.e., more likely to accurately perceive both flashes when the limb travels the fastest). Also, we observed that participants were as likely to experience the fusion illusion in the resting control condition than early in the movement (i.e., at low limb velocity). Therefore, this study suggests that visual information processing is enhanced at high limb velocities, and that is, at least compared to auditory processing.

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36.425 The auditory flash-drag effect: Distortion of auditory space by visual motion

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A brief visual flash presented in the presence of visual motion is displaced in the direction of motion (Whitney and Cavanagh, 2000). The mechanisms mediating this flash-drag effect remain unknown. Here we investigated whether the effect extends cross-modally to surrounding auditory space. In a 2AFC method of constant stimuli task, observers judged the laterality of brief auditory bursts presented from one of six closely spaced azimuthal speaker positions while viewing a full-field sinusoidal grating translating horizontally. The grating did not overlap spatially with the speaker positions. We found that reported auditory positions were skewed in the direction of visual motion. Unlike other spatial cross-modal effects such as the ventriloquism effect, or its aftereffect, there was no manipulation of visual stimulus location, only a manipulation of visual motion within a constant location. Further, there is no 'fusion,' 'grouping,' or 'binding' of a visual and auditory object in this case; the location of the background motion was non-overlapping and was never confused with the location or identity of the auditory burst. Our results demonstrate a cross-modal flash-drag effect and suggest a shared influence of motion on visual as well as auditory spatial representations.

36.426 Consistent frequency-based sound matches to natural visual scenes

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We previously demonstrated a consistent relationship between visual spatial-frequency and auditory amplitude-modulation (AM) frequency, in which Gabors of 0.5-8 cycles/degree (c/d) were linearly matched to auditory AM frequencies of 1-12 Hz (Guzman et al., VSS 2009). Here, we investigated whether similar crossmodal associations occur for natural scenes, which are dominated by various spatial-frequency components. We asked whether people consistently match specific auditory AM frequencies to photographed scenes, and if so, how these crossmodal matches are associated with the dominant spatial-frequency component and subjective impression (dense, stimulating) of the scene. We found that eighteen observers matched specific auditory AM frequencies to 26 scenes from diverse categories (nature, urban, indoor) with surprising consistency. We applied a 2D Fourier transform to each scene to determine the contrast energy for 12 spatial-frequency bins ranging 0.05-12.8 c/d. Interestingly, scenes with higher contrast energy in the mid-spatial-frequency range 0.5-1.25 c/d were matched to faster AM frequencies, whereas other spatial-frequency components did not contribute to AM frequency matches. Analysis of our images suggests that scenes with stronger mid-spatial-frequency components appear to have numerous object boundaries. Thus, the results

suggest a crossmodal association between the visual coding of multiple object boundaries and the auditory coding of AM frequency. Furthermore, a multiple regression of AM frequency matches to subjective scene ratings (obtained after the experiment) indicates that dense (vs. sparse) and stimulating (vs. calm) ratings independently contribute to faster AM frequency matches. Based on the spatial-frequency analysis and subjective ratings, our results demonstrate an association between visual object density and faster auditory AM frequencies in scene perception, and that visual features conveying stimulating content additionally contribute to faster AM frequency matches.

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36.427 Irregular sound rhythm magnifies the temporal sequential effect in audiovisual temporal ventriloquism

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Temporal ventriloquism can be seen in the auditory capture of visual Ternus apparent motion, where the percepts of apparent motion ("element motion" vs. "group motion") are modulated by two sounds presented close in time to the visual events. Here we presented a sequence of tones in association with the Ternus display and examined the temporal sequential effect in audiovisual ventriloquism. In Experiment 1, the Ternus display was synchronized with the first, middle and last two tones in the sequence, which had 6 beeps presented rhythmically. The threshold of perceiving "group motion" decreased over its temporal location in the auditory sequence. In Experiment 2, the tone sequences contained either 4 or 6 beeps. The sequential effect was observed in both sequences but the effect size was determined mainly by the relative temporal position of the visual display. Experiment 3 employed the 6-beep tone sequences with either regular or irregular tempo. The sequential effect was evident in both sequences, but was larger for the irregular. Experiment 4 used the same design as Experiment 3 but with one extra beep and one-to-three extra beeps at the sequence-beginning and sequence-ending positions, respectively. The sequential effect was replicated in the irregular sequence but diminished in the rhythmic sequence. These results can be accounted by a time averaging model, according to which the observer builds up time-based expectancy based on the averaged time intervals between beeps; it is relatively easy to separate the two frames in the Ternus display when the time interval between the two visual frames matches this expectancy. The more the beeps are heard, the stronger the expectancy is, and the lower threshold of "group motion". Moreover, because time averaging is delayed when fewer beeps in irregular sequence are heard, the threshold is higher at earlier positions, magnifying the temporal sequential effect.

36.428 Binding brightness and loudness: what attention filters can observers achieve for dynamic audiovisual displays?

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Purpose. This study investigated the ways in which observers can combine dynamic visual and auditory information. Method. The observer viewed a quick stream of 18 gray disks (83 ms per disk), each accompanied by a simultaneous burst of auditory white noise. Three levels of disk brightness and of noise loudness were used to produce 9 different types of audiovisual pairing. In the brightness-only (and loudness-only) attention condition, participants attempted to ignore variations in loudness (brightness) and judged with feedback whether the mean brightness (loudness) of the disks in the stimulus stream was higher versus lower than the usual. In the correlation condition, participants judged (with feedback) whether the stimulus stream contained a greater number of correlated (brightest/loudest plus dimmest/quietest) or anticorrelated (brightest/quietest plus dimmest/loudest) pairings. In each condition, a probit model was used to measure the impact exerted on the observer's judgments by each of the 9 types of pairings. Results. In the brightness-only and loudness-only conditions, observers succeeded in ignoring the irrelevant modality. In the correlation condition, the impact of a pairing was a separable function of its brightness and loudness. Conclusions. Depending on task demands, observers can achieve a range of different attention filters for processing these audiovisual displays: they can extract either the mean loudness (uninfluenced by

brightness variations) or the mean brightness (uninfluenced by loudness variations); however, they can also achieve an attention filter that correlates the loudness with the brightness variations in the stimulus stream.

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36.429 Synchrony and Temporal Order Judgments For Simple and Complex Stimuli

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We investigated differences in the point-of-subjective simultaneity (PSS) and temporal integration window (TIW) across audiovisual stimulus type and task (van Eijk et al, 2008). Participants (n=28) completed two tasks in separate blocks, 1) in synch or out of synch - synchrony judgment task (SJ), 2) visual or auditory first - temporal order judgment task (TOJ). Five stimulus types were used: point-light-drumming (PLD), audiovisual speech (FV), single beep-flash (BF), single beep-flash with constant visual information (BFV), and beep-flash sequence with the timing properties of PLD (BFD). Each was presented at one synchronous and 10 asynchronous levels (5 audio-leading, 5 video-leading). Best-fitting Gaussian curves to the number of synchronous and visual first responses were calculated for SJ and TOJ data, respectively. PSS was derived as the peak of the SJ curve and the 50% point of the TOJ cumulative curve. TIW was taken as the standard deviation of the Gaussian curve for each task. Visual inspection of fits revealed that, 1) no participants managed to do TOJ for BFD stimuli; 2) less than 50% could do TOJ on complex stimuli (FV and PLD); 3) ~90% were able to do TOJ on BF and BFV stimuli; 4) ~85% were able to do SJ for all stimuli. Interestingly, PSS for SJ were all video leading, regardless of stimulus type, while they were all audio leading for TOJ, in line with previous research (Petrini et al 2010). Using only participants able to do SJ for all stimuli (n=23) we conducted one-factor ANOVAs on PSS and TIW data. Stimulus type influenced both PSS ($F(8,4)=11.363$, $p<0.001$) and TIW ($F(8,4)=23.837$, $p<0.001$). Only four subjects were able to do the TOJ on all stimulus types (excluding BFD). Overall, TOJ is a harder task than SJ; both PSS and TIW differed as a function of stimulus type and tasks.

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36.430 The way of multisensory spatial processing with audiovisual speech stimuli differs in single and bilateral visual presentations.

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Ventriloquism is defined as a shift of perceptual location of a sound source toward a synchronized visual stimulus. Previous studies lead to the conclusion that the size of the ventriloquism effect is regulated by physical, not cognitive, factors. However, this conclusion is based upon simplified experimental designs which typically entail pairs of single audio and visual stimuli. Such designs do not capture our responses to a multisensory world where many signals impact various sensory modalities. We examined the hypothesis that cognitive factors, as well as physical ones, modulate the ventriloquism effect in complex situations. We used audio-visual speech stimuli in two experiments involving simplified (Experiment 1) and complex (Experiment 2) designs. Experiment 1 involved presentation of one movie of a face and one voice whereas Experiment 2 involved presentation of two bilateral movies and one voice. In both experiments a cognitive factor, namely congruency of speech and visual stimuli, was varied (congruent, incongruent). In both experiments visual stimuli appeared on a central CRT monitor, whereas auditory stimuli were presented from 13 positions, created by left (L)- right (R) phase differences. Participants judged if the location of an auditory source was left or right of a central fixation cross (on the monitor). In Experiment 1, we found no differences due to cognitive factors. Consistent with previous finding, the auditory localization bias did not differ as a function of congruency. In Experiment 2, we manipulated physical saliency between bilateral visual stimuli as a physical factor, as well as congruency of audio-visual syllables as a cognitive factor. In this experiment, both visual stimulus saliency and audio-visual congruency elicited relatively large auditory localizations biases. In conclusion, these experiments show that a cognitive factor affects the way audio-visual spatial information is integrated in a more complex, real world, situation.

36.431 Detecting synchrony in degraded audio-visual streamsKeshav Dhandhanian¹(keshav57@mit.edu), Jonas Wulff², Pawan Sinha¹; ¹Dept. of Brain and Cognitive Sciences, MIT, ²RWTH Aachen University

Even 8-10 week old infants, when presented with two dynamic faces and a speech stream, look significantly longer at the 'correct' talking person (Paterson & Werker, 2003). This is true even though their reduced visual acuity prevents them from utilizing high spatial frequencies. Computational analyses in the field of audio/video synchrony and automatic speaker detection (e.g. Hershey & Movellan, 2000), in contrast, usually depend on high-resolution images. Therefore, the correlation mechanisms found in these computational studies are not directly applicable to the processes through which we learn to integrate the modalities of speech and vision. In this work, we investigated the correlation between speech signals and degraded video signals. We found a high correlation persisting even with high image degradation, resembling the low visual acuity of young infants. Additionally (in a fashion similar to Graf et al, 2002) we explored which parts of the face correlate with the audio in the degraded video sequences. Perfect synchrony and small offsets in the audio were used while finding the correlation, thereby detecting visual events preceding and following audio events. In order to achieve a sufficiently high temporal resolution, high-speed video sequences (500 frames per second) of talking people were used. This is a temporal resolution unachieved in previous studies and has allowed us to capture very subtle and short visual events. We believe that the results of this study might be interesting not only to vision researchers, but, by revealing subtle effects on a very fine timescale, also to people working in computer graphics and the generation and animation of artificial faces.

36.432 The role of prior knowledge in development of visual-auditory integrationRhiannon Thomas¹(Rhiannonlthomas@gmail.com), Denis Mareschal¹, Marko Nardini²; ¹Centre for Brain and Cognitive Development, Birkbeck college, University of London, ²Department of Visual Neuroscience, UCL, Institute of Ophthalmology

Recent research suggests that children do not combine multisensory information in an optimal manner until at least eight years (Nardini et al, *Curr Biol.* 2008; Gori et al, *Curr Biol.* 2008). Bayesian models propose that observers take into account the reliability of signals received, the prior probability of a given object or event, and the prior probability that two sensory events have the same cause (Körding et al, *PLoS One*, 2007). Children might not integrate multisensory cues if they lack prior knowledge about event pairings. We studied children's and adults' (1) propensity to bind different sounds with a visual event, and (2) their ability to learn new visual-auditory associations for interpreting events. Children aged 6, 8, and 10 years and adults judged whether moving balls appeared either to bounce or to pass without bouncing (Sekuler et al, *Nature* 1997). Collisions were accompanied by either beeps, white noise inclining in amplitude, white noise declining in amplitude, or silence. Each participant was re-tested after a training phase in which they saw unambiguous bounce events paired with one of these sounds. These initial results come from groups trained with the beep stimulus only. Before training, children were less influenced by a beep in their perception of the visual event than were adults, but the influence was stronger in 10 year olds than in younger children. Younger children were also less influenced by training with the new sound pairing than 10 year olds or adults. This study is the first to track performance in the "audiovisual bounce illusion" across this age range. We found an extended developmental trajectory for both the interpretation of visual events in light of auditory information, and the ability to learn new visual-auditory pairings. This is consistent with the hypothesis that prior knowledge is a factor limiting children's multisensory perception.

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36.433 The Influence of Aging on Audio-Visual Temporal Order JudgmentsChris M. Fiacconi¹(fiaccocm@mcmaster.ca), Emilie C. Harvey¹, Allison B. Sekuler^{1,2}, Patrick J. Bennett^{1,2}; ¹Department of Psychology, Neuroscience, and Behaviour, McMaster University, ²Centre for Vision Research, York University

Perception of naturalistic events often requires observers to integrate stimuli across visual, auditory, and tactile modalities. There is some evidence that the temporal resolution of cross-modal integration may be impaired in older subjects. For example, Poliakoff et al. (2006) reported that just notice-

able differences (JNDs) in a visual-tactile temporal order judgment (TOJ) task were larger in older subjects than younger subjects. However, little is known about how aging affects the temporal precision of audio-visual integration, especially for non-speech stimuli. We therefore measured the effects of aging on the precision of temporal order judgments in 11 younger (19-26) and 8 older (70+) subjects. On each trial, a subject was presented with a single visual stimulus (i.e., Gabor pattern) and a single auditory stimulus (i.e., Gaussian-damped tone), and the task was to determine which stimulus was presented first. The stimuli were brief (<10 ms) and clearly super-threshold. The method of constant stimuli was used to vary the temporal offset between stimuli, and the resulting psychometric function for each subject was used to estimate the point of subjective simultaneity (PSS) and JND (i.e., the standard deviation of the best-fitting cumulative normal). One younger subject who had a JND that was more than 5 standard deviations above the mean was declared an outlier and not included in further analyses. For the remaining subjects, the mean PSS ($t(16) = 0.14$, $p = 0.88$) and JND ($t(16) = 0.08$, $p = 0.93$) did not differ between age groups. Hence, we found no evidence that aging affects the temporal precision of auditory-visual temporal judgments, at least in this simple task. Currently we are investigating the extent to which this result generalizes to more complex audiovisual events.

36.434 Enhanced Audiovisual Processing in People with One EyeStefania S. Moro¹(smoro@yorku.ca), Jennifer K. E. Steeves¹; ¹Centre for Vision Research, York University

Previous research has shown that people with only one eye have enhanced spatial vision implying sensory compensation for their loss of binocularity. We investigated whether the loss of one eye may lead to enhanced multisensory processing as a result of cross-modal sensory compensation. In Experiment 1, we measured speeded detection and discrimination of auditory, visual and audiovisual targets presented as a stream of paired familiar objects and sounds in people with one eye and controls viewing binocularly or with one eye patched. We found that all participants were equally able to detect the presence of auditory, visual or bimodal targets. However, when asked to discriminate between the unimodal and bimodal targets both control groups demonstrated preferential processing of visual over auditory information with the bimodal stimuli -- the Colavita visual dominance effect. Moreover, participants with one eye, showed no Colavita effect and demonstrated equal preference of processing visual and auditory stimuli, suggesting better multisensory integration. In Experiment 2, we increased the temporal processing load by asking participants to detect and discriminate back-to-back stimulus repetitions in a stream of paired familiar objects and sounds expecting that auditory performance will dominate due to the tasks' temporal nature. Preliminary results indicate that all participants are equally able to detect the presence of auditory, visual or bimodal repetitions, however, when asked to discriminate between the unimodal and bimodal repetitions, the Colavita effect persists in both control groups. However, participants with one eye show no Colavita effect, and again demonstrate equal preference of processing visual and auditory stimuli. These results indicate that binocular viewing controls consistently demonstrate visual dominance, even when auditory dominance is expected but participants with one eye display equal auditory and visual processing, likely as a form of crossmodal adaptation and compensation for their loss of binocularity.

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36.435 Effects of auditory information on the rubber hand illusionMasakazu IDE¹(ide@rikkyo.ac.jp), Yoshihisa OSADA¹; ¹Rikkyo University, Saitama, Japan

Purpose: Research on the rubber hand illusion has ever emphasized the role of visual information in locating a tactile sensation on the rubber hand. However, auditory information also serves to locate the tactile sensation along with visual information. Even without visual information, the tactile sensation is produced by a tactile stimulus presented together with auditory stimulus (Hotting and Roder, 2004). We investigated the effect of auditory stimulus on the rubber hand illusion and tactile intensity.

Method: Participants were shown a mirrored image of a left rubber hand but not allowed to see their own left hand directly. Tactile stimuli were given to the participant's own hand and the rubber hand with bars ever 2000 ms under three complex sound conditions (SS (Simultaneous Sound)

condition, DS (Delayed Sound) condition, NS (No Sound) condition). The participants were asked to evaluate perceived ownership of the rubber hand and perceived intensity of the tactile sensation in their own hand.

Result: Perceived ownership of the rubber hand differed with each sound condition. In SS condition, the participants perceived significantly higher ownership of the rubber hand than in DS or NS condition ($SS > DS$; $p < .01$, $SS > NS$; $p < .05$). Perceived intensity of tactile sensations also differed with each complex sound condition. In SS condition the participants perceived significantly higher intensity of tactile sensations ($SS > DS$; $p < .01$, $SS > NS$; $p < .01$). These results imply that only when presented simultaneously with a tactile stimulus, the auditory stimulus enhances the perceived ownership of the rubber hand and the tactile intensity, and hence also influences the rubber hand illusion.

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Attention: Neural mechanisms II

Sunday, May 8, 2:45 - 6:30 pm

Orchid Ballroom, Poster Boards 436 - 451

36.436 Representation of visual feature conjunctions in the superior parietal lobule

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Color and form are initially processed in parallel in separate units of the visual system. Feature binding describes the process that integrates the distributed information of various feature dimensions which occur at one location. While patient studies suggested that posterior parietal cortex is necessary for binding of features from different visual dimensions, imaging evidence has been inconclusive in the past. One major problem was that the comparison of visual search for feature conjunctions is more difficult than single feature search. To circumvent this confound, we compared the processing of features and feature conjunctions in an identical search task. Functional data of the occipital and parietal cortex were acquired in 1.4mm isotropic voxels using a 7T MR-scanner. As visual search displays, configurations of five Gabor patches were briefly presented to the subjects. These configurations differed in the combination of color and spatial frequency on fixed radially arranged positions. Two values per dimension - red and green, high and low spatial frequency - formed four specific Gabor patch types. The twelve subjects performed a singleton-conjunction search task during brain imaging. This task demands the integration of both feature dimensions at a specific location. In a multivariate pattern analysis a support vector machine was applied on the BOLD signal using a searchlight algorithm. Individual accuracy maps for classification of displays were obtained which just differ in their colors, spatial frequencies or the conjunction of both feature dimensions. In the group analysis we found superior parietal and parieto-occipital regions which encode single feature dimensions. One area of the left superior parietal lobule (MNI-coordinates x -26, y -54, z 68) shows superadditive classification accuracy for feature conjunctions compared to the individual feature classification accuracies. We conclude that this area is involved in the representation of 'true' conjunctions of visual feature dimensions.

36.437 Attention is a state of mind: Phase of ongoing EEG oscillations predicts the timing of attentional deployment

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Attention is rapidly deployed in response to external or internal cues. However, experimental measurements of the speed of this deployment find large variability across trials. Beyond neuronal and measurement noise, some of this variability could depend on the specific state, or phase, of an ongoing "attention cycle", with specific moments leading to faster deployment than others. To test this, we present a 'clock' with a single hand rotating at 1Hz. After a variable period, the rim of the clock briefly turns red. Observers (n=13) indicate the position of the hand at this cue onset. The difference

between the reported and veridical positions, called latency, specifies the speed of attentional deployment for this trial. We find large within-observer variance in attentional latencies across trials ($SD=54\pm 5$ ms). As predicted by the cyclical hypothesis of attention, this variance can be partly explained by the strong linear-to-circular correlation between trial-by-trial latencies and the corresponding phase of EEG oscillations. Significant ($p < 10^{-12}$) correlations are found at 7 Hz in occipital cortex, 50 ms before cue onset, and at 16 Hz in frontal cortex, 60 ms after cue onset. Each area accounts for roughly 5-6 ms of trial-by-trial variability. Compensating for the variance contributed by one area leaves the influence of the other intact and vice-versa, indicating that the two contributions are independent. Based on these findings, we propose that attentional selection involves two distinct stages. First, under sustained attention, the state of occipital activity in the theta (5-10 Hz) range determines the speed of attentional capture by the cue. Following this, attention samples the position of the moving clock hand for later report; the timing of this sampling depends on the state of frontal areas in the high-alpha, low-beta (12-20 Hz) range. Together, the two effects determine the timing of attentional allocation.

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36.438 Gamma-band activity reflects differential selection-for-action before single and double saccades

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Synchronizations in the gamma range have been proposed to mediate top-down attention signals. Here we combined high-resolution eye tracking and EEG recording to study the neural mechanisms involved in the visual selection of upcoming movement goals.

Upon onset of an endogenous cue participants had to execute either single or double saccades to peripheral targets. We analyzed the EEG activity during the short reaction time interval between cue onset and start of the speeded saccadic response. Additionally, we tested the deployment of visual attention during movement preparation with a secondary letter discrimination task.

A frequency domain analysis of the EEG signals revealed an increase in occipital/parietal gamma band activity before saccade onset. This peak in gamma band activity temporally coincided with covert attention shifts to the saccade goal(s) as measured by the secondary letter discrimination task. The gamma response was even more pronounced before the initiation of double saccades, reflecting the visual selection of the additional saccade goals. The eye-tracking data suggest that the gamma response was not induced by microsaccades.

We therefore propose that neural synchronization in the gamma range co-occurs with the attentional selection of intended saccade goals and the involved sensori-motor transformations. Moreover, these neural synchronizations are modulated by the amount of motor goals that need to be prepared.

36.439 Source localization of an event-related potential indexing covert shifts of attention in macaques

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Although, human event-related potentials (ERP) provide precise temporal resolution of the neural activity underlying covert attentional selection, this method is uninformative about the source of that neural activity within the brain. Previously, we showed that ERPs recorded from macaque monkeys evidence an N2pc component (N2-posterior-contralateral) homologous to that found in human subjects when attention is covertly shifted during visual search (Woodman et al. 2007 PNAS). In the present work, we sought to test the hypothesis that the neural networks generating the monkey N2pc (or m-N2pc) are similar to those of humans. Previous work modeling the neural generators of the human N2pc found that there are two temporally and spatially distinct subcomponents: an initial parietal activation followed by activity in ventral extrastriate cortex (Hopf et al. 2000 Cereb Cortex). In the current study the neural generators of the m-N2pc were modeled using electrophysiological and structural MRI data for electrical source analysis using CURRY 6 (Neuroscan). A 3-D reconstruction of the head and cortical surface was created using the boundary element method. Distributed (current density) and local (dipole) sources were calculated. For the current density analysis Low Resolution Electromagnetic Tomography (LORETA)

was used. Local source analyses were modeled with a single moving dipole. Both methods indicated a source in extrastriate visual cortex, generally corresponding to the human data but with a unique temporal sequence.

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36.440 Who's controlling the brakes? Pulsed inhibitory alpha EEG is linked to preparatory activity in the fronto-parietal network measured concurrently with the event-related optical signal (EROS).

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Alpha oscillations have an inhibitory influence on visual processing and fluctuate with both sustained and directed attention. We have proposed a role for these 8-12 Hz oscillations as a pulsed inhibition of ongoing brain activity, given that alpha's inhibitory influence fluctuates as a function of its phase. An important prediction of this theory is that top-down signals from the fronto-parietal network elicit changes in this pulsed inhibitory alpha activity over visual cortex. We tested this prediction by measuring preparatory neural activity in the fronto-parietal network using the event-related optical signal (EROS), which affords high temporal and spatial resolution, while concurrently measuring oscillations in alpha activity over visual areas with the electroencephalogram (EEG). We tested the influence of this brain activity on visual awareness by having subjects perform a metacontrast masking task. Extending our previous findings, both EEG and EROS showed oscillations in parietal areas in the period before the target presentation, with the phase of these oscillations predicting subsequent target detection. We also replicated previous findings showing that decreases in alpha power predict target detection, verifying their inhibitory role in visual processing. The pre-target EROS activity in right pre-frontal and parietal areas also predicted subsequent target detection. Crucially, these increased differences in EROS activity between detected and undetected targets correlated negatively with EEG alpha power across subjects. Furthermore, sorting the EROS data based on single trial EEG alpha power revealed that EROS frontal activity was associated with decreased alpha power, whereas subsequent parietal activity was associated with increases in alpha power. Together, these results provide support for our theory that alpha oscillations represent pulsed inhibition of ongoing activity. These data further suggest that these oscillations may be controlled by top-down influences from the fronto-parietal attention network.

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36.441 Higher levels of alpha event-related desynchronization are associated with the attentional blink

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Accuracy at detecting or identifying a second target (T2) is reduced when it is presented within 500 ms of a first target (T1) in a rapid serial visual presentation (RSVP). This limitation of visual attention is referred to as an attentional blink (AB). Cognitive control models of the AB propose that the combination of limited attentional resources and inappropriate management of attention by top-down cognitive control underlie the AB. Reducing the amount of attentional investment with an additional task or instructing the use of a more relaxed cognitive approach have been found to reduce the magnitude of the AB. As well, personality and affective traits, as well as affective states, associated with a broader or more flexible cognitive approach have been found to predict smaller AB magnitudes. Previously, event-related desynchronization (ERD) in the alpha range has been used to measure attentional investment in anticipation of an imminent visual stimulus. In the current study alpha ERD was used to investigate whether the degree of attentional investment in anticipation of an RSVP trial was related to performance outcomes on the AB task. A sustained alpha ERD was observed during a 2-second foreperiod preceding the RSVP stream. As hypothesized, greater alpha ERD before the RSVP trial, indicating greater anticipatory attentional investment, was found on short lag trials where an AB was present (inaccurate T2 performance) compared to short lag trials where an AB did not occur. However, on trials where T2 was presented after a longer interval relative to T1, greater alpha ERD before the RSVP trial was found on trials with accurate T2 performance relative to trials

where T2 was incorrect. Results support models of the AB that propose greater attentional investment underlies the AB, and furthermore that this attentional investment is prepared in anticipation of each RSVP trial.

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36.442 Neural decoding during continuous task performance

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In cognitive neuroscience, multivariate pattern classification methods are typically used to discriminate between the spatial patterns of neural responses acquired using fMRI. However, these methods are also effective for capitalizing on the multivariate nature of high temporal resolution, single-trial electroencephalography (EEG) data. For instance, in perceptual decision-making tasks, EEG-based pattern classifiers can predict stimulus category and observer decisions (Philiastades and Sadjja, 2006), and can outperform traditional ERP metrics in predicting individual differences in behavior (Das et al., 2010). Here we investigated whether these findings generalize to a continuous performance task. Observers viewed images of faces and cars embedded in noise (Das et al., 2010) presented in rapid serial visual presentation sequences (2 Hz) that lasted two minutes. There were four separate EEG sessions of 12,000 trials that each differed in terms of target probability (5%, 10%, 25%, 50%). A linear discriminant analysis was used to classify stimulus category (face/car) and performance (hits/misses). As in previous studies, classification accuracy discriminating stimulus type was high (mean peak classifier accuracy: 67.7%). The time-course of this discriminatory activity peaked at approximately 300 ms post-stimulus and was strongly modulated by target probability, suggesting that the pattern classifier is likely capturing modulations in the P3 ERP component. Unlike previous studies, we found no evidence of discriminatory information about the target during the time window of the face-selective N170 ERP component. Our classifier also predicted observer performance significantly better than chance, albeit with lower success than stimulus category (mean peak classifier accuracy: 58.0%). The inclusion of EEG spectral features improved classification of performance, but not classification of stimulus type. Our results demonstrate that pattern classification algorithms can be used successfully with a continuous performance task, and that the temporal and spectral features driving classification performance are highly task dependent.

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36.443 Attentional Modulation of Chromatic and Achromatic Visual Evoked Potentials by Task Relevant Stimuli in Separate Hemi-fields.

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Prior research has shown that the chromatic pattern-onset VEP recorded along centerline (OZ) is robust to attentional manipulations when test and distractor stimuli are either superimposed or spatially separated. These results suggest that the chromatic VEP response is occurring early (V1) and may not be sensitive to feedback from attentional mechanisms. We report here studies of chromatic and achromatic VEP responses recorded over V1 on the centerline (Oz) and lateralized over each hemisphere (O1 and O2) in the presence of distractor and test stimuli located in disparate hemifields. VEP were recorded to both distractor and test simultaneously using a frequency-tagged averaging technique. Results indicated that for stimuli that are equated in psychophysical magnitude and using a distractor similar to the test, small but significant attentional modulations of the chromatic waveform amplitudes are revealed. In addition, we explore effects of attentional modulation across both the chromatic (L-M) and (S-(L+M)) and the achromatic visual pathways. The results suggest that the Chromatic Onset VEP is robust to attentional effects unless the distractor is similar to the test and the task is difficult. Under such conditions small but significant attentional affects can be revealed.

36.444 Using Feature-based Attention to Examine the Hierarchical Structure of Visual Processing

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Object perception is achieved through a hierarchically organized, yet highly interconnected network of brain areas. The functionality of this hierarchy can be studied using feature-based attention. For example, directing attention to lower-level features such as contours modulates orientation-sensitive mechanisms in early visual areas. However visual areas associated with object processing can also be targeted. We have recently shown that feature-based attention to contours produced late modulations associated with ventral-occipital areas, compared to early effects in extrastriate areas when cueing attention to motion. To further elucidate the procedural structure of object perception and the role feature-based attention plays, we used a difficult object recognition task by presenting fragmented "pillows" or "flowers" among random black and white lines, and investigated the mechanisms of cueing feature-based attention to the colour or shape of the objects. We predicted that invalid colour cues will incur large perceptual costs because filtered colour lines will need to be retraced. Invalid shape cues are less costly since retracing relates to later stages of object processing. These predictions were tested in two studies. In each, we recorded event-related potentials (ERPs) while participants were cued (80% validity) to either shape or color. When cued to shape, their task was to indicate the colour of the object, and when cued to colour they were asked to report its shape. Behaviourally, we found a cueing effect in both experiments, but it was stronger when expecting colour. Our ERP and spectral analysis results revealed that attending to shape produced modulation at 250 ms. Attending to colour, however, generated effects first, from 80-160 ms, and later between 460-580 ms. These effects can be attributed to early contour integration processes during easier valid trials and large temporal costs for difficult invalid trials. Our data support a hierarchical cost model of perceptual decisions.

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36.445 The combination of visuospatial cues and Transcranial Magnetic Stimulation (TMS) on the human Frontal Eye Fields (FEF) facilitates conscious visual detection

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Prior evidence has shown that cue-mediated spatial attentional orienting has the potential to modulate several aspects of visual performance such as spatial frequency and contrast discriminations. Similarly, Transcranial Magnetic Stimulation (TMS) on attentional areas has yielded short-lasting visual performance modulations. We explored the effects of TMS on the right Frontal Eye Field (FEF), an attentional orienting relevant area, alone or in conjunction with visuospatial cueing, and gauged its ability to enhance perception of low-contrast near-threshold Gabor stimuli. Three groups of participants took part in the three experiments of this study. In every trial, participants were required, after the presentation of a Gabor stimulus, to perform two tasks: (1) A forced choice categorization task, consisting of determining the orientation of the Gabor lines (Left or Right?) and (2) a detection task (Did you see the stimulus? Where?). In Experiment 1, the Gabor was preceded by a spatially predictive visuospatial cue. In Experiment 2, the Gabor was preceded by a single TMS pulse delivered on the right FEF. Finally, in Experiment 3 the Gabor was preceded by both, the cue and the TMS pulse. In Experiment 1, we replicated previous findings demonstrating enhancements of visual perception at locations indicated by a predictive visuospatial cue. In Experiment 2, time-locked isolated TMS pulses showed a very mild potential to modulate any of the two tasks. Interestingly, the combination of a single TMS pulse on the right FEF with a visuospatial cue in Experiment 3 resulted in significant bilateral enhancements of conscious visual detection, beyond the levels achieved using the cue alone. Our results suggest an important role of the FEF in conscious visual perception. More importantly, they reveal the potential and limitations of TMS pulses alone or combined with visuospatial cueing to punctually boost conscious visual performance, setting up a path for further explorations.

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36.446 The attentional blink impairs localization but not enumeration performance in an "enumerating-by-pointing" task

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Earlier we reported (Haladjian & Pylyshyn, 2010) that observers are able to rapidly and accurately enumerate up to six items when using an "enumerating-by-pointing" method (compared with the typical subitizing limit of four). We have been exploring possible reasons for this increase. The present study examines the role of increased encoding time (without increasing actual viewing time) by testing whether two presentations of the stimulus separated by a variable interval improves enumeration performance. Additionally, this allowed us to test if the second presentation of the stimulus was sensitive to the attentional blink. Participants were shown masked displays that contained 2-9 randomly-placed black discs (~1° diameter) on a gray background. The stimulus was presented once for 100-ms or presented twice for 50-ms (each) with a delay of 200-, 400-, or 600-ms (ISI) between the mask offset and the second presentation onset. Participants then marked the locations of each disc using a computer mouse.

Trials with two separate 50-ms presentations showed better enumeration performance than trials with a single 100-ms presentation for numerosities >4; the delay conditions did not significantly differ from each other (except in 5-item displays). For localization performance, two-presentation trials produced more accurate responses than single-presentation trials for numerosities <7. Here, location accuracy was significantly better in the 600-ms delay condition for displays with 5-8 items. This suggests an additive benefit when presenting the second display outside of the attentional blink in trials where observers needed to enumerate >4 items. These results (that the attentional blink affects localization more than enumeration) suggest that attention is more critical for the encoding of location information than for enumerating small sets. These results also point to the possibility that the increased coding time associated with the mouse pointing (when marking object locations) may play some role in the increased subitizing limit.

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36.447 Attention boosts neural population response via neural response synchronization

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[Purpose] Visual attention enhances neural responses to an attended stimulus by neural response gain control. It has been also pointed out that attentional enhancements of neural responses originate from neural response synchronization (e.g. Fries et al., 2001; Kim et al., 2007). In this study, we adopted a steady-state visual evoked potential (SSVEP) technique in an attempt to investigate the relationship between the neural response amplitude and the neural response synchronization. [Experiment] SSVEP is an oscillatory brain potential evoked by a continuously flickering visual stimulation and can be identified as EEG components corresponding to the flicker frequencies. It has been shown that the visual attention modulates the amplitude and phase of the SSVEP. We recorded SSVEPs for two stimuli flickered at different temporal frequencies which were presented on the left and right sides of the fixation. An arrow-shape cue was presented on the center of the display to control participants' state of attention. Participants were instructed to shift their attention to a flickering stimulus in the side pointed by the cue. We analyzed the amplitude (thought to reflect the magnitude of neural population response) and phase coherence (thought to reflect neural response synchronization) of SSVEP. [Results] Both the SSVEP amplitude and phase coherence were increased by visual attention and the correlation between the two measures was very high ($r > 0.55$). Time course analysis of the two SSVEP measures showed that attentional modulation for the phase coherence started earlier than that for the amplitude. These results indicate that visual attention boosts neural population response via neural response synchronization.

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36.448 Effects of cognitive training on attention allocation and speed of processing in older adults: An ERP study

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It is well established that humans experience declines in visual cognition with age, including a slowing in the speed of cognitive processing and in shifts of visuospatial attention (Madden et al., 2005; Salthouse, 1996). The P3 ERP component is useful in understanding the relationship between cognitive decline and aging, as its latency and amplitude are thought to index the speed and efficiency of stimulus evaluation and attentional resource allocation, respectively. A plethora of studies have shown that P3 latency increases and amplitude decreases with age, reflecting a slowing of stimulus evaluation processes and a deficit in the amount of attentional resources allocated during this. In addition, the N2pc component, a correlate of the allocation of visuospatial attention, also has been shown to increase in latency and decrease in amplitude with age (Lorenzo-López et al, 2008), reflecting age-related slowing and reduction of attentional resource allocation. Here, we investigate the effectiveness of speed of processing (SOP) training in improving older adults' processing speed and attentional allocation in a visual search task, evidenced by changes in the P3b and N2pc components after training. SOP training is a cognitive intervention involving computerized attention and memory tasks, designed to enhance perceptual processing and processing speed of visual stimuli. Before and after 20 hours of SOP training, ERPs were recorded while older adults searched for a singleton feature target defined by an orientation difference to the distractors. Results indicate that SOP training increases the amplitudes of both the P3 and N2pc and decreases the latency of the P3 in response to a target pop-out. Results suggest that SOP training enhances both visual processing speed and the allocation of attention to relevant stimuli in older adults. Behavioral performance and ERP differences in relation to young adult participants and older controls (without training) will also be discussed.

36.449 Age-related differences in processing task-irrelevant stimulus properties: a single-trial ERP study

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We quantified age-related differences in processing task-irrelevant stimulus properties. In each trial, thirteen young (<32 years old) and ten older (>60 years old) participants saw one of two pre-learned faces colourised with red or green tones at one of eight phase noise levels while scalp ERPs were recorded. In one condition, subjects had to discriminate between the identities of the two faces ignoring colour, whereas they had to ignore face identity and discriminate colour in the other condition. Behavioural accuracy followed a noise dependent sigmoid in the identity task: older participants had a significantly higher 75% correct discrimination threshold and a lower maximum accuracy. Whereas in the colour task, performance was independent of the noise level and both groups showed equally high accuracy (above 98%). For each individual in the two tasks the time-course of phase noise sensitivity was obtained by entering ERPs into a single-trial general linear model [<http://www.biomedcentral.com/1471-2202/9/98>]. The model identified variations in neural activity statistically associated with changes in phase noise while regressing out the main ERP differences due to identity, colour and task. Group level analysis indicated that young adults showed higher noise sensitivity in the identity task than in the colour task between circa 170 and 270 ms post-stimulus, whereas older adults did not show any task differences. Results from our study, as well as from other recent studies that reported the absence of task effects in old participants in a variety of visual attention paradigms, suggest that the ability to process only relevant visual information may be compromised in all older adults. However, individual subject analysis revealed that most older subjects did show task modulations whose timing and duration varied extensively. We suggest that individual subject single-trial analysis is a useful tool which provides a deeper insight into age-related changes in top-down visual processing.

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36.450 Decoding object-based attention signals in the human brain

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Visual attention can be directed to spatial locations and various features, as well as to a unitary object independently of spatial and feature variations. Previous work has shown object-based attention can modulate neural activity in category-selective areas in the ventral visual cortex. However, whether earlier visual areas can be modulated by object-based attention and how higher-order areas control and represent the deployment of object-based attention is not clear. To investigate the neural mechanism of object-based attention, we presented two superimposed objects with similar shape that occupied the same spatial location, and asked participants to perform an attention-demanding task on one of the objects. We observed enhanced fMRI response for object-attended condition compared to a neutral condition in a network of occipital-parietal-frontal areas. There was no difference in overall sustained fMRI response between attending to different objects in any attention task regions. Using multivariate pattern analysis (MVPA), however, we successfully "read out" the attended object from activity patterns in both early visual areas (V1 to MT+), object-selective areas (lateral occipital complex, LOC), and some parietal and frontal areas (e.g., IPS, MFG, and SFG). These results indicate that neural activity in multiple visual areas can be modulated by object-based attention. Furthermore, parietal and frontal cortical regions contain neural signals related to priority of attended object.

36.451 Single-trial ERP modelling reveals how task constraints modulate early visual processing

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We used a parametric design to study how task constraints modulate the relationship between single-trial ERPs and image noise. We used two pictures of faces equated in amplitude spectra and colourized with red and green tones. We added varying amounts of noise to the phase spectra. Thirteen subjects saw these faces in identity and colour discrimination tasks. Behavioural accuracy followed a noise dependent sigmoid in the identity task; it was high and independent of noise level in the colour task. Using a similar design, Philastides, Ratcliff & Sajda [J. Neurosci. 2006, 26(35), 8965-75], suggested that brain activity before 200 ms is not modulated by task constraints, followed by a time-window sensitive to top-down influences. We used a single-trial ANCOVA [Rousselet et al. *Frontiers in Psychology* 1:19] to assess task modulation of ERP noise sensitivity while regressing out the main ERP differences due to identity, colour and task. Group analyses showed a reduction in noise sensitivity in the colour task compared to the identity task around 140-300 ms post-stimulus onset. A bootstrap spatial-temporal statistical analysis in every subject revealed more complicated results: significant task modulation occurred in 8/13 subjects, one showing an increase and 7 showing a decrease in noise sensitivity in the colour task. Onsets and durations of effects also differed between group and single-trial analyses, so that at any time point only 4 subjects showed results consistent with group analyses. A shift function analysis revealed non-uniform task effects on ERP distributions: decreased noise sensitivity in the colour task was due mostly to a modulation of single-trial ERPs to faces, not noise. In conclusion, single-trial analyses suggest that [1] early face processing can be modulated by task demand, at least in some subjects; [2] substantial individual differences in the time-course of task modulations speak against group statistics to study these effects.

Attention: Models

Sunday, May 8, 2:45 - 6:30 pm

Orchid Ballroom, Poster Boards 452 - 457

36.452 A model of performance in whole and partial report experiments

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Performance in whole and partial report experiments is described well by Bundesen's Theory of Visual Attention (TVA, Bundesen, 1990). TVA assumes that perceptual processing of objects occurs in parallel and is constrained by a limited processing capacity, which is distributed among target and distractor objects and determines the rate of processing. A race model describes encoding into a limited visual short term memory (VSTM) following perceptual processing. The model employs the processing and VSTM capacity limits, a temporal delay before perceptual processing starts and a filtering parameter quantifying the difference in perceptual processing for target and distractor objects in order to model performance in whole and partial report experiments with varying number of targets and distractors. Here we introduce a simpler model of encoding into VSTM. Rather than assuming a race between objects, so that the order in which objects completes perceptual processing determines which objects are encoded, this new model simply conditions the probability of encoding a number of objects on the constraint that the capacity of VSTM is not exceeded. This new model reduces the algebraic complexity of TVA and fits data from previous whole and partial report experiments (Shibuya and Bundesen, 1988) better using the same number of free parameters.

36.453 Visual attention in spatial cuing and visual search

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Signal detection theory (Green & Swets, 1966) based uncertainty models (Palmer, 1994; Eckstein, 1998) with an unlimited capacity attention system have provided an excellent account of the set size effects in visual search accuracy. However, spatial cuing task experiments found strong effects of attention --- precuing improves accuracy, especially when the target is embedded in high level of external noise (Doshier & Lu, 2000, Lu & Doshier, 2000). In this research, we attempted to resolve the apparent contradictory conclusions from these two major lines of inquiry in spatial attention. We hypothesize that the conditions under which an effect of spatially cued attention is substantial should correspond to the circumstances in which attention effects over and above uncertainty should occur in visual search. Many of the classical visual search experiments have been carried out using stimulus conditions where attention effects are least likely to be found. We studied visual search in a range of external noise, signal contrast, and target-distractor similarity conditions. In each trial, 8 Gabor patches were shown in each of two brief intervals, with one target at a different orientation from the distractors in one of the presentations. Subjects were precued to a subset of the stimuli (1, 2, 4 or 8) and asked to report (1) which interval contained the target, and (2) where the target was. In both zero noise and low signal contrast, and all high external noise conditions, the set size effects were greater than that predicted from decision uncertainty model. All these results are well accounted by a model that combines the elaborated perceptual template model (ePTM, Jeon, Lu & Doshier, 2009), the attention mechanisms developed in the PTM framework (Lu & Doshier, 1998), and the SDT based uncertainty calculations. Our empirical results and theoretical model generate a common taxonomy of visual attention in spatial cuing and visual search.

36.454 On a distinction between detection and discrimination: metacognitive advantage for signal over noise

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Informal reports suggest that subjects often find it awkward to rate their confidence after responding "no" in a detection task. This is formally captured by findings that metacognitive sensitivity (i.e., the ability to distinguish correct from incorrect stimulus judgments using confidence ratings) is greater for stimulus presence than for stimulus absence (Fleming & Dolan, 2010; Kanai et al., 2010). However, on a signal detection analysis, such results could be expected to arise from first-order stimulus properties, such as unequal variance between target present and absent distributions, rather than from differences at the level of metacognitive function (Maniscalco & Lau, in review). Here we provide evidence that even when first-order stimulus properties were taken into account by a signal detection model, metacognitive sensitivity was higher for stimulus presence in two "genuine" detection tasks, in which the target absent condition was characterized by an absence of evidence/stimulus energy. A control task in which subjects distinguished between a Gabor pattern and visual noise did not show the same effect-- presumably because a transient presentation of visual noise can also be taken as an instance of stimulus presence, thus rendering the task a discrimination between two categories. One interpretation is that a "yes" response in a detection task means that the subject has introspective access to stimulus processing, which can be used to guide accurate metacognition. This account is consistent with the notion that confidence judgments are made by high-level mechanisms that evaluate earlier perceptual processing (Maniscalco & Lau, in review; Rounis et al., 2010; Pleskac & Busemeyer, 2010; Fleming et al., 2010). These results can inform a principled distinction between detection and discrimination: although traditionally both tasks are modeled with a detection model with two distributions, detection is more than just discriminating between two categories (signal vs noise), because the "signal" yields higher metacognitive advantage over "noise."

36.455 Fast and slow dynamics in learning and attending to objects: Transient Where and sustained What stream inputs explain individual differences

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How are spatial and object attention coordinated to achieve invariant object learning and recognition during eye movement search? How do prefrontal priming and parietal spatial mechanisms interact to determine the reaction time costs of intra-object attention shifts, inter-object attention shifts, and shifts between visible objects and covertly cued locations and their effects on individual differences (Brown and Denny, 2007; Roggeveen et al., 2009)? The current work builds on the ARTSCAN model (Fazl, Grossberg and Mingolla, 2009) of how spatial attention in the Where cortical stream coordinates stable, view-invariant object category learning in the What cortical stream under free viewing conditions. The earlier model predicted how 'attentional shrouds' (Tyler and Konsevich, 1995) are formed when surface representations in cortical area V4 resonate with spatial attention in posterior parietal cortex (PPC), and how active surface-shroud resonances support conscious surface perception. Our work clarifies how interactions of fast transient Where stream inputs from cortical area MT and slow sustained What stream inputs from V4 influence both PPC and prefrontal cortex (PFC), whose interactions with V4 explain psychological data about covert attention switching and multifocal attention without eye movements. The relative strength of transient and sustained attention-enhancing inputs explains all cases in the experiments cited above, including individual differences in reaction time for invalid cues. Moreover, volitional control of the strength of inhibition between shrouds simulates performance differences in useful-field-of-view tasks (Green and Bavelier, 2003), and separated left and right cortically magnified hemifield representations simulates allocation of independent attention resources in left and right visual hemifields (Alvarez and Cavanagh, 2005).

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36.456 **Assessing models of visual saliency against explicit saliency judgments from one hundred humans viewing eight hundred real scenes**

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Researchers have proposed computational models of visual saliency, which have been assessed against observers' saccadic eye movements during free viewing (Parkhurst, Law, & Niebur, 2002; Itti & Koch, 2001; Peters et al., 2005; Schumann et al., 2008) and visual search (Itti & Koch, 2000; Torralba et al., 2006). Surprisingly no studies have evaluated saliency models against explicit observer judgments of visual saliency. Here, we compare saliency model predictions (Walther & Koch, 2006) to saliency judgments of one hundred observers. Methods: We used 800 natural images displaying common indoor and outdoor scenes with varying numbers of objects. One hundred human observers were instructed to view each image and click on the most salient location of each image. We evaluated the saliency model by quantifying the proportion of human-reported most salient locations falling within circular regions (with radii varying between 21.06 and 107.44 pixels) containing the top five salient model predictions. As a baseline condition, we evaluated the agreement between the model and one hundred randomly generated saliency selections. Results: Across all observers and images the proportions of explicit saliency reports within the top five model predictions were: 0.102, 0.068, 0.057, 0.047, 0.044 (0.31 ± 0.21 across all top five saliency predictions). In contrast, the agreement of model predictions with the randomly generated saliency selections was 0.08 ± 0.03 . Thus, our findings show a modest agreement between model saliency predictions and human explicit judgments, but significantly larger ($t = 13.86$, $p < 0.001$) than expected by chance. The methods presented can serve as a protocol for evaluation of other saliency models (Bruce & Tsotsos, 2006; Zhang et al., 2008) and comparisons of models' ability to predict explicit saliency judgments vs. saccadic eye movements.

36.457 **Quantifying the relative influence of photographer bias and viewing strategy on scene viewing**

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Saccade distributions while observers freely watch natural scenes and videos are often found to be highly biased toward the image center (center-bias effect) (Tatler, 2007). Our quantitative comparison of 30 saliency models over three standard datasets of still images (Bruce & Tsotsos 2006, Kootstra et al., 2008 and Judd et al., 2009), shows that model rankings do not agree. Interestingly, a trivial central Gaussian blob saliency model outperforms many models in regard to predicting where humans look. Two main sources of center-bias are: photographer bias (natural tendency of photographers to place objects of interest near the center) and viewing strategy (tendency of subjects to look at the center to extract more information)(Tseng et al., 2009). In this study, we measure the relative influence of these causes and introduce a less center-biased dataset as a benchmark for fair evaluation of models. From four datasets (three aforementioned and Le Meur et al., 2006), we chose those images with the lowest center-bias index (a defined measure of tendency of human saccade density maps to be concentrated toward center) and selected just 187 out of overall 1250 stimuli. The average center-bias index of accepted images, all original stimuli and Gaussian blob were 0.61, 0.76(0.88 for Judd) and 1, respectively. Next, to remove the variability in eye recording parameters in datasets, we recorded eye movements of 30 subjects watching these images. The center-bias index for recorded eye movements over selected images and the Judd dataset were 0.76 and 0.861, respectively. After removing the first saccade, these values dropped to 0.68 and to 0.845. Although selected images had less objects at the center, there was still a great amount of saccade density at the center. Our results suggest that, 1) Widely used datasets are center-biased, 2) Photographer bias could be reduced, and 3) Viewing strategy has a higher influence than photographer bias on overall center-bias since removing photographer bias does not reduce overall center-bias significantly.

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Perceptual learning: Models

Sunday, May 8, 2:45 - 6:30 pm

Vista Ballroom, Poster Boards 501 - 513

36.501 **The Modelfest Perceptual Learning Initiative: A Status Report**

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Between ten and twenty years ago a broad range of perceptual learning (PL) results featured the lack of transfer across locations, tasks and features, implicating changes in early visual cortical areas. It held out promise for a simple unifying model of PL. In subsequent years the story has grown more complicated. Novel experimental protocols, many of which are summarized in Sagi's review "Perceptual Learning in Vision Research" (Vision Research (2010), doi:10.1017/j.visres.2010.10.019 or go to PubMed), show that learning can surprisingly transfer to untrained locations. Our recent results show that the learning can be transferred to untrained retinal locations and features even if an irrelevant task was used in one arm of the double training protocol. Competing principles have been formulated by several researchers for understanding this new data, but a concrete computational model to actually predict the data is lacking. The computational models that have been developed are generally used to predict the modelers own restricted data. In physics, where acquiring data is often costly, the researchers have come together to share in collecting critical data. This enables the computational modelers to test and distinguish among the competing models. The perceptual learning community has recently adopted this approach to collect a large trustworthy dataset for comparing models. At the 2010 Perceptual Learning Workshop in Israel, the Modelfest perceptual learning initiative was launched. The group considered not only what would be critical experiments, but also hidden methodological and statistical issues. This presentation reports on the current status of the ModelfestPL group's effort. In addition we will open up discussion for the next stage of the ModelfestPL deliberations.

Acknowledgement: National Eye Institute

36.502 **Perceptual Learning without Awareness: a Motion Pattern Gated Reinforcement Learner**

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Problem. Perceptual learning increases the performance of detecting motion directions even if the observer is not aware of the presented motion direction (Watanabe et al., Nature 2001). The results suggest that training with a sub-threshold stimulus affects the neural sensitivity and leads to an increase of decision performance for stimuli above threshold. Which mechanisms of cortical motion processing are involved and how do neural mechanisms of learning account for this achievement?

Method. We propose a neural model of visual motion and motion pattern detection (based on Raudies & Neumann, J. of Physiology Paris 2010). Model V1 detects local motion signals that are integrated in model MT. Spatio-temporal configurations of MT responses are further integrated in model MSTd. Feedback signals from MSTd to MT modulate the activity of MT neurons. MSTd responses are temporally integrated in model LIP which generates a decision. The strength of the connections between MSTd neurons and a decision unit in LIP can be adapted using motion pattern gated reinforcement learning (compare Roelfsema et al., Trends in Cognitive Science 2010). Since sub-threshold stimuli are used for training the maximum input activation in LIP drives this adaptation rather than its output activities. Furthermore, the sum of the connection weights is fixed which decreases the influence of signals induced by task-irrelevant features due to the normalization and also keeps the weights in bounds.

Results. Model simulations quantitatively replicate the findings of Watanabe et al. as there is an improvement of detection performance at an average of 10.8% for stimuli above threshold after the training with sub-threshold stimuli. Due to the normalization of the weights of the connections from MSTd to LIP our model predicts that if two, instead of one, motion directions were trained, the improvement on the decision performance will drop about a third to approximately 7%.

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36.503 A Multi-Location Augmented Hebbian Reweighting Model (m-AHRM) of Transfer in Perceptual Learning

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Specificity or partial specificity to either a retinal location or to stimulus dimensions is one hallmark of perceptual learning. Recent literature suggests that the degree of specificity (or transfer) may depend on task precision, extent of initial training, or pre-training of locations. Position and feature (i.e., orientation) specificity has been taken to imply a key locus of visual representation in early visual cortex. For learned changes rooted in early representations, specificity is the default and the challenge is to explain transfer. Previously, an augmented Hebbian reweighting model (AHRM) (Petrov, Doshier, & Lu, 2005, 2006) has modeled perceptual learning at a single location as reweighting of inputs from early representations to a decision unit. This model successfully predicts the effect of feedback and training accuracy on learning. Here, we report results of a new multi-location-extension to the AHRM (m-AHRM) (Doshier, Jeter, Liu, & Lu, ms) that includes higher-precision location-specific representations and a lower-precision representation shared over a broad set of locations. The m-AHRM then uses reweighting mechanisms to generate implications for transfer to tasks that differ in position or in feature from the original training task. The model predicts differences in level of specificity (or transfer) when a new task involves changes in orientation, changes in location, or both – correctly predicting our results of more transfer to same-orientation judgments in new locations and least transfer to new orientation judgments in the same location. The model also accounts broadly for limitations in transfer to high-precision judgments due to the lower precision of the multi-location representations. In a related abstract (Liu, Lu, & Doshier, VSS 2011), we consider how the m-AHRM accounts for position pre-training ('double training') tasks. The m-AHRM advances our understanding of the nature and mechanisms of transfer in perceptual learning.

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36.504 Optimality predicts transition to specificity in perceptual learning

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In any given task, there are at least two broad classes of strategies that can be utilized to select actions. Model-based strategies simulate a model to select actions that maximize expected performance, while model-free policy-based strategies learn mappings between stimuli and response options specific to training examples (i.e. no generalization). A natural trade-off exists between these strategies, wherein model-based out-perform model-free under conditions of stimulus variability and limited training, while abundant training on few stimuli favor model-free strategies. These ideas predict when specificity should occur – in experimental conditions in which policies outperform predictive models. We tested this prediction using a motion extrapolation task that supports both model- and policy-based strategies. We predicted participants would transition to policy-based strategies and exhibit specificity in learning only under conditions where policy-based strategies were more reliable. We quantified these conditions (e.g. stimulus set sizes and training durations) by simulating performance of a model-based Kalman filter and policy-based Q-learning algorithm. For 200 training trials, 4 paths (4P) predicts transition, while 20 paths (20P) does not. The task required selecting the reemergence location (one of 20 bins) of a dot that traveled along a circular arc of variable curvature and orientation before disappearing behind an occluder. Separate groups were trained in the 4P and 20P conditions. We monitored observers' extrapolation strategies through no-feedback pre-test, post-test, and interleaved test sessions among training sessions. While both groups performed similarly during pre-test, relying on default models, transition to a policy-based strategy occurred only in the 4P condition, resulting in improved performance on trained stimuli, but decreased performance on novel stimuli. The results

comprise the first quantitative prediction and successful test of when specificity in learning will occur, and show that specificity should result whenever response policies are the most reliable way to satisfy task demands.

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36.505 Statistical summary perception interferes with statistical learning and vice versa

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The visual system is an efficient statistician, extracting statistical summaries over sets of objects (statistical summary perception; SSP), as well as statistical regularities between individual objects (statistical learning; SL). While both of kinds of statistical processing have been studied extensively, their relationship is currently unknown. Here we examine whether, and how, SSP and SL influence each other. Observers were familiarized to displays that were constructed, without their knowledge, from spatial pairs of oriented lines that could only be learned based on statistics of co-occurrence. In Experiment 1, we examined whether SSP influences SL for these pairs by manipulating the task performed during familiarization. Fifty-four observers were randomly assigned to one of three tasks: passive viewing, summary (judging mean line orientation vs. vertical meridian), or control (detecting the presence of duplicate orientations). SL, expressed in a subsequent forced-choice familiarity test (chance=50%), was reliable in passive viewing and control conditions (56.3% and 65.3%, respectively), but significantly weaker in the summary condition (48.6%). These results do not reflect dual-task interference per se (because of the control condition), but suggest that SSP in particular hinders SL. In Experiment 2, we examined whether SL influences SSP by manipulating the presence of statistical regularities during the summary task. Twenty new observers were randomly assigned to one of two conditions: structured (summary condition from Experiment 1), or random (grids generated like before, but positions scrambled on each trial). Performance on the summary task (chance=50%) was reliable in structured and random conditions (56.6% and 64.0%, respectively), but significantly worse for structured. These results suggest that the presence of statistical regularities (even if not ultimately learned) hinders SSP. In sum, we find bidirectional interference between extracting statistical summaries and learning statistical relationships. These findings are consistent with competition for shared statistical resources and/or dependence on different modes of attention.

36.506 Learned bias for 3-D shape perception without object motion

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Visual signals, such as retinotopic location and object translation direction can be recruited as cues that influence the perceived rotation direction of 3D objects (e.g. Haijiang et al., PNAS, 2006; Harrison & Backus, J Vis, 2010). However, all of these stimuli contained motion, so the learning could have been idiosyncratic. For example, training could have caused bias in MT neuron populations jointly tuned for motion and disparity.

We tested whether location and grating orientation can be learnt as cues to 3-D shapes in absence of motion signals. In Experiment 1, stimuli depicted a perceptually ambiguous dihedral angle (book cover). On training trials observers' percept was controlled using disparity, occlusion and luminance cues; stimuli were presented above or below fixation with location and stimulus configuration correlated. In Experiment 2, stimuli depicted a 3D zigzag shape with the two end surfaces (out of three attached surfaces) being frontoparallel; this stimulus was also ambiguous and one or the other frontoparallel surface looked closer on each trial. On training trials observers' percept was controlled using disparity and luminance cues. The end surfaces were textured using oriented hatching and their depth-order was correlated with hatching orientation during training. Ambiguous test stimuli were pseudo-randomly interleaved with training stimuli to measure learning.

In Experiment 1, observers' (N=8) perceived configuration on test trials was consistent with the location-configuration correlation. The bias was evident on the next day. No learning was observed in Experiment 2 (N=6). Thus, location-dependent biases are a general property of the visual system and "priors" (in a Bayesian sense) for interpreting ambiguous stimuli can

be learned at specific retinotopic locations, presumably due to retinotopic organization of the early visual system. Cues that are more abstract, such as texture orientation, presumably require more extensive training.

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36.507 A cascade-correlation model of bistable perception

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The phenomenon of bistability arises from physical ambiguities in the stimulus that lend themselves to two mutually exclusive interpretations. Many properties have been shown to affect switching rate, including stimulus interruptions (Kornmeier et al., 2007), attention (Meng & Tong, 2004), and eye movements (Ellis & Stark, 1978). However, relatively little research has addressed the role of individual differences. Previous studies have found that subjects fall into two groups: fast switchers and slow switchers (Borrellino et al., 1982). It has been suggested that these differences arise from variations in individual experience with the stimulus (Sakai et al., 1995). In this study, we use a sibling-descendant cascade-correlation neural network (Baluja & Fahlman, 1994; Shultz, 2004) to examine this hypothesis. We trained the network on a set of unambiguous stimuli, then tested it on an ambiguous stimulus, modeled after the Necker cube. Networks with extensive training showed high switching rates, while networks with shorter training regimes showed significantly lower switching rates. In addition, we found that strong positive feedback yielded lower switching rates, while weak positive feedback resulted in higher switching rates. Dynamical models support the latter result, where rivalry depends on a balance between positive self-feedback and mutually inhibitory connections between neural populations (Wilson, 1999). Our model suggests that switching rates may also depend on the underlying neural architecture, which in turn depends on early network training and experience.

36.508 Cue recruitment for extrinsic signals after training with low-information stimuli

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Jain, Fuller and Backus [PLoS ONE, 2010] reported that cue recruitment did not occur for three cues that were extrinsic to a rotating Necker cube. In other words, auditory and visual signals that were not conveyed by the object itself (so they were extrinsic to the cube) were not discovered and utilized by the visual system as cues that influenced the apparent rotation direction of the cube. However, research during the last year has shown that stronger learning can occur when training stimuli are not completely disambiguated by long-trusted cues, but rather are seen to have one conformation or the other as forced by priming with perceptual perseveration [Harrison and Backus, *Vis Res*, 2010; van Dam and Ernst, *J Vis*, 2010; Di Luca, Ernst, and Backus, *Cur Biol*, 2010]. We tested whether training with these "low-information" stimuli could cause an extrinsic signal to be recruited as a cue for apparent rotation direction of a 3D Necker cube. Cubes rotated about their vertical axis and were surrounded by an annular random-dot field rotating either clockwise or counter-clockwise in the plane of the display. The rotation directions of the random-dot field and Necker cube were correlated on training trials. At training trial onset, binocular disparity was present for 150 ms to control the percept for the entire trial (duration 1.5 s). Test trials contained the rotating field of dots but did not contain disparity, so cube rotation was ambiguous. Each session contained 96 training trials followed by four blocks (96 trials each) of mixed test and training trials in pseudo-random order. Under these new conditions, the random-dot field was recruited and utilized as a visual cue. The effect was small (58% seen as trained vs. 50% for chance). Thus, an extrinsic signal was learned when training stimuli had low information.

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36.509 Evaluative Conditioning with Mental Imagery

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Evaluative conditioning typically involves a neutral perceptual stimulus and one that can trigger an emotional response. During conditioning the emotional response becomes associated with a previously neutral stimulus, so that the once neutral stimulus will now trigger an emotional response in isolation. There is strong evidence that mental imagery can involve perceptual mechanisms in early visual cortex. We hypothesized that if visual

imagery does involve the same mechanisms as visual perception then we should be able to condition mental images in a manner similar to perceptual stimuli. During the conditioning phase of the experiment participants were instructed to imagine one of two oriented and colored gratings, after which a positive or negative emotional photograph was displayed (counter-balanced). During the test phase participants made judgements on the emotional content of a different set of pictures in a choice reaction time task. Shortly before each photograph was displayed one of the two previously imagined oriented gratings were briefly presented perceptually. We found that reaction times were faster when the emotional content in the photo matched the conditioned emotion of the oriented pattern during the imagery-conditioning phase (congruent pairing) and slower when it did not match (incongruent pairing). In addition, when the orientation of the perceptual test patterns was manipulated independently to color the RTs changed in a predictable manner consistent with known characteristics of early visual cortex. These data suggest that the previously neutral imagery patterns had taken on emotional value and this carried over to the perceptual stimuli (generalization).

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36.510 The effect of confidence hysteresis on numerical discrimination

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The present research investigates the effect of confidence on perceivers' ability to make visual discriminations. Confidence is affected by the difficulty of the discrimination at hand. Here we show that it also depends on the perceivers' confidence during preceding discriminations; i.e., confidence is state-dependent. The evidence for state-dependence takes the form of confidence hysteresis: How well 4-6 year old children and adults perform in a two-alternative forced-choice numerical discrimination task depends on whether they have had a prior history of easier discriminations or of harder ones. Participants had to identify whether a set of blue or yellow dots was larger by number; in these tasks, the numerical ratio of the two sets determines the difficulty of the judgment, and lower ratios (e.g., 11:10 dots) result in poorer performance, and, presumably, lower confidence, that higher ratios (e.g., 22:10 dots). We manipulated confidence by placing participants in either an Easy-to-Hard condition, where all the easiest trials were at the start, or in a Hard-to-Easy condition, where all the hardest trials were at the start. Additionally, in the first experiment, we gave participants accurate feedback after every trial. Both children and adults performed significantly better on the Easy-to-Hard compared to the Hard-to-Easy condition, suggesting that confidence hysteresis modulated their performance. The effect was especially pronounced for the Hard-to-Easy children, whose performance was so poor that it resembled the discrimination abilities of 9-month old infants; it is as if the children had "given up", despite having the ability to discriminate the two sets. In the second experiment, we removed external feedback. The adults still showed a significant difference between the two conditions, but the children did not, suggesting a developmental change in the effect of feedback on perceptual confidence.

36.511 Contributions of visual and temporal similarity to statistical learning

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Objects appear in reliable patterns over time, and these regularities are extracted with visual statistical learning (VSL). Prior VSL studies have focused on learning of arbitrary groups of objects. However, objects are not grouped arbitrarily in the natural environment, and instead often have some degree of visual similarity: multiple views of the same object, or multiple objects from a particular context (e.g., grocery stores or forests). VSL may exploit visual similarity to learn temporal statistics. Here we investigate the contributions of visual similarity and temporal co-occurrence (temporal similarity) to VSL. Observers viewed sequences of fractal images presented one at a time while performing an orthogonal task. Unbeknownst to them, the images were grouped into eight pairs: four where images always occurred successively (high temporal similarity) and four where images occurred successively 1/3 of the time (low temporal similarity). Two pairs in each condition contained images that were each other's color inverse (high visual similarity), and the remaining pairs' images were unrelated

(low visual similarity). We administered a surprise familiarity test for VSL in which observers viewed a pair and rated their familiarity using a slider. High temporal similarity pairs were rated as more familiar than low temporal similarity pairs, providing evidence for VSL and revealing sensitivity to subtle probabilistic gradations. There was also an effect of visual similarity, but in the opposite direction: high visual similarity pairs were rated as less familiar than low visual similarity pairs ($p < 0.05$). We are investigating this surprising effect in a follow-up behavioral study using an implicit measure, and a follow-up fMRI study examining the impact of temporal and visual similarity on neural representations. Preliminary results suggest that high temporal similarity and low visual similarity increase pattern correlations in medial temporal lobe sub-regions. These studies begin to characterize how VSL operates over naturalistic visual regularities.

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36.512 Top-down inferences affect visual sensitivity in a signal detection task.

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Sensory inputs are noisy and under-constrained, and it has been suggested that people perform probabilistic inference over these inputs in order to infer the most likely state of the world. But does probabilistic inference occur at the lowest levels of sensory processing and to what extent does it affect our percepts? We explored this question by asking whether inference occurs in a visual signal detection (SD) task. In the traditional SD model (Green & Swets, 1966), sensitivity (d') to a signal is unaffected by whether people infer the parameters of the signal and no-signal distributions. However, according to more recent probability matching models (in which people respond in proportion to the inferred probability of a signal), beliefs about signal discriminability should affect d' ; therefore, we can use d' to probe whether people perform inference in a SD task. Here, we presented subjects with a SD paradigm in which we manipulated their beliefs while keeping sensory inputs constant. Specifically, when they reported low confidence, subjects in the 'signal-present' group were told that the signal was present regardless of whether the stimulus was actually presented. Subjects in the 'signal-absent' group were told that the signal was absent. If individuals are not performing inference over the signal and no-signal distribution parameters, then there should be no change in d' for either group. If they are, we predict significantly worse sensitivity for the 'signal-present' group compared to the 'signal-absent' group. Consistent with the latter prediction, we found a significantly lower d' ($p < 0.03$) for the 'signal-present' ($d' = 1.61$) versus the 'signal-absent' group ($d' = 1.95$). Our results suggest that people learn the statistics (i.e. signal mean and noise) of the SD distributions in real time using top-down information, that this learning is well-predicted by an ideal Bayesian observer model, and that this inference immediately affects sensitivity.

36.513 Humans adaptively use temporal correlations in stimulus history to estimate velocity

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Motivation: We have previously shown that perceptual estimates of stimulus velocity are biased toward both the velocity mean of previously viewed stimuli and the velocity of the immediately preceding stimulus (Kwon and Knill, VSS 2010). The bias toward the mean was modulated by the variance of stimulus velocities, consistent with optimal statistical inference. Subjects' behavior, however, showed that they assumed temporal correlations that didn't exist in the stimulus set. Here, we tested whether observers can adapt their estimation strategies to take into account different temporal correlation functions in stimulus history. Method: We used a motion extrapolation task in which a target moved and disappeared behind an occluder and subjects had to hit the target when it was supposed to be in the designated hitting zone. The velocity of the target was randomized from trial to trial, but could have either a positive or negative correlation with the previous velocity ($r = .6$ or $-.6$). The occluder width was randomly varied in such a way that there was no temporal correlation in target's occlusion time from trial to trial. Results: As before, the timing of subjects' hitting behavior showed velocity biases toward the mean velocity of the stimulus set. In the positive correlation condition, they showed a strong bias toward the velocity of the immediately preceding stimulus, but the bias disappeared in the negative correlation condition. Subjects' behavior was well fit by an optimal model

that adaptively took into account sensory uncertainty in velocity estimates, occluder width and the temporal statistics of the stimulus sequence, but with a strong positive bias in the estimated temporal correlations in the stimuli. Conclusions: The CNS accurately and adaptively accounts for the temporal statistics of stimuli when estimating velocity, but has a positive bias in its estimated temporal correlation function.

Perceptual learning: Neural mechanisms

Sunday, May 8, 2:45 - 6:30 pm

Vista Ballroom, Poster Boards 514 - 528

36.514 A new role of feedback: facilitating stabilization of perceptual learning after training

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A number of studies have examined the role of response feedback (informing an observer of performance accuracy) during training in perceptual learning and found that feedback increases the magnitude and speed of learning (Herzog and Fahle, 1998, 1999). Here we present evidence for a new role of feedback: feedback stabilizes perceptual learning, making it more resilient against deterioration/adaptation that occurs due to an excessive amount of continuous trial performance (Mednick et al, 2005, Censor et al, 2009). In the experiment, 12 subjects were trained on a motion detection task. Subjects were trained on two randomly interleaved motion directions for 3 days. One direction was always paired with response feedback, while the other was not. Pre-tests and post-tests were conducted in which performance was measured not only for the two trained directions but also a spread of surrounding directions. No feedback was provided during these tests. Performance changes after training were calculated for the first half (early) trials and second half (late) trials of the test stages for each direction. For the direction trained with feedback and its vicinity, significant learning was observed in both the early and late trials. On the other hand, for the direction trained without feedback and its vicinity, while significant learning was observed for the early trials, this learning effect completely deteriorated in the late trials. We conclude that feedback not only increases the magnitude of learning, as previously found, but also stabilizes learning to be resilient to deterioration or adaptation. [NIH R01 (EY015980, EY019466, AG031941, MH091801)]

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36.515 Symbol learning is faster and more 'fluent' in young macaque

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Ten monkeys were trained to choose between pairs of dot patterns or pairs of symbols using in-cage touchscreens. Four juvenile monkeys learned the symbols faster than six adults and achieved a higher facility for symbols, but not for dots. Adult and juvenile reaction times were similar for dots, but juveniles were faster than adults in choosing between symbols.

New symbols were introduced in ascending value order. The adults treated each new symbol as unknown in value and required hundreds of trials to realize its value, whereas the juveniles showed an iterative learning pattern, accurately valuing novel symbols within the first few trials.

Thus the juvenile monkeys learned symbols faster than the adults and achieved more facility with the symbols than the adults. This study extends into the cognitive domain numerous previous studies showing that the brains of young animals are more plastic than adult brains.

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36.516 The role of contiguity and contingency in visual perceptual learning

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Visual perceptual learning (VPL) is defined as a long-term improvement in performance on a visual task. A recent study has shown that VPL of a stimulus feature results from repetitive presentation of the feature paired with reward (Seitz, Kim and Watanabe, 2008, Neuron). This suggests that

at least some types of VPL are highly related to the theory of conditioning. An important question is whether VPL involves conditioning. However, there are two types of conditioning, classical conditioning and instrumental conditioning, which are subserved by different neural mechanisms (O'Doherty et al., 2004, *Science*). Thus, if VPL that is reinforced or formed by reward involves conditioning, the mechanism for VPL that occurs in a classical conditioning procedure should be different from that in an instrumental conditioning procedure. To address these questions, we trained one group with a classical conditioning procedure (Kim, Seitz, Watanabe, 2008, VSS), and the other group with the instrumental conditioning procedure in which subjects performed a go no-go task by choosing between pressing (go) or not pressing (no-go) a button, in response to one of three orientation stimuli. In the "go" condition, the reward was delivered according to a different reward probability (80%, 50%, 20%) of each orientation. In the no-go condition, the reward was delivered with a constant probability of 50%. Whereas VPL induced by goal-directed instrumental conditioning is governed by the rule of contingency (Rescorla, 1968), VPL that occurs in the classical conditioning procedure follows the rule of contiguity, according to which two events are associated if they repeatedly occur together in time. These suggest that the underlying mechanism between classical conditioning induced VPL and goal-directed instrumental conditioning induced VPL are different. These further suggest that there are more than one mechanisms for VPL.

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36.517 Diurnal variation of glucocorticoids appears to modulate V1-specific perceptual learning

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Research has shown that learning deficits may occur due to excessive glucocorticoid exposure. Furthermore, human striate cortex (V1) has been found to contain a significant concentration of glucocorticoid receptors (Perlman et al, 2007). We examined whether V1 perceptual learning was affected by diurnal glucocorticoid variation. Learning was assessed using a classic texture discrimination task (Karni & Sagi, 1991). Research suggests that TDT learning is V1 specific (Schwartz et al, 2002), and that visual-cortical plasticity is likely NMDA-receptor mediated (e.g., Bear, 1996). Learning deficits in the presence of heightened glucocorticoid exposure suggests that these steroids may modify V1 functionality. For training, participants were grouped according to endogenous glucocorticoid phase: (1) during AM, before 11:30 (high levels), (2) during PM, between 12:30-7:00 (low levels), and (3) an exploratory PM group concurrently using antidepressant (serotonin-selective reuptake inhibitor/SSRI) medications. Percent correct was measured as a function of seven SOA (stimulus-onset asynchrony) levels. Results were fitted with Weibull functions, and threshold was interpolated at 75% correct. No effect of learning was observed for those trained during AM hours, however, increases in task efficiency were noted (i.e., fitted slope change). Those trained during PM hours showed significant overall sensitivity increases (i.e., shift in psychometric function). The AM group showed significantly higher cortisol levels versus the PM group, as determined by enzyme-linked immunosorbent assay. The SSRI group showed no effect of learning between sessions. Performance differences between AM and PM groups were expected, as heightened glucocorticoid levels are known to impair hippocampus-dependent memory (e.g., Domes et al, 2005). Therefore, we reasoned a similar mechanism may be present in V1. The lack of performance improvement within the SSRI group was unexpected. Previous research has suggested that NMDA-receptor functionality may be modified by SSRIs (Raabe & Gentile, 2008), and thus comparable plasticity changes may be occurring in V1.

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36.518 The effects of naps on the magnitude and specificity of perceptual learning of motion direction discrimination

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Perceptual learning is a persistent and specific improvement in the performance of a perceptual discrimination. Previous research found that perceptual learning of a texture discrimination task is sleep-dependent (Karni et al. 1994) and that repeated, within-day testing leads to percep-

tual deterioration that is specific to the trained condition (Mednick et al. 2005). Daytime naps mitigate this deterioration (Mednick et al. 2002) and can even lead to improvement in task performance within the same day (Mednick et al. 2003). We studied the effects of daytime naps on perceptual learning of a motion direction discrimination task (Rokem and Silver, 2010). Following training on this task, subjects were classified into one of four groups: 50-90 min naps with or without rapid eye movement (REM) sleep, measured with polysomnography (PSG), Quiet Wake (75 min with eyes closed, no sleep, monitored with PSG), and Active Wake (subjects who continued their day as usual). Similar to previous findings of perceptual deterioration in the trained condition, we found decreased performance in the trained motion direction without sleep (all subjects, prior to the nap). In addition, subjects who napped (REM + non-REM) exhibited increased perceptual learning in the trained direction of motion, after the nap, relative to non-nappers (active wake + quiet wake). No such effect of napping was found for learning in an untrained direction of motion. Furthermore, among REM nappers, the number of minutes spent in REM sleep was significantly correlated with the specificity of perceptual learning (defined as the difference between the amount of learning in the trained direction and in the untrained direction). We conclude that sleep plays an important role in the consolidation of learning of motion perception and that REM sleep promotes stimulus specificity of perceptual learning.

36.519 Learning to Attend Induces an Increased Response to Unattended Stimuli

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Traditional perceptual learning tasks employ just a single stimulus feature, making it difficult to parse out the differential effects of low-level sensory plasticity (i.e. Seitz et al., 2009) and top-down attentional gain modulations (i.e. Fahle, 2009) on observed changes in behavior and neural activity. Here, we evaluated the relationship between learning and top-down attentional gain using feature-selective fMRI techniques and a task that required discriminating one of ten possible orientations (instead of only a single orientation, as is typically employed in perceptual learning studies). Given that perceptual learning has been documented to occur without attention (Seitz et al., 2009), we expected to see an increase in the amplitude of orientation-selective response profiles in V1 after training on both an orientation-attended and an orientation-unattended task. Five subjects participated in an initial fMRI scan session, 10 behavioral training sessions, and a final scan session. For all sessions, subjects performed four blocks of an orientation discrimination task and four blocks of a rapid serial visual presentation (RSVP) letter task. Before training, the orientation-selective response profile in V1 had higher amplitude during the orientation-attended task compared to the orientation-unattended (RSVP) task. However, after training, the amplitude of the orientation-selective response profile increased, particularly when orientation was ignored (i.e. during the RSVP task). These results indicate that practice improves feature-selective representations of stimuli in early visual cortex, even when the stimulus is not being actively attended. Moreover, since our experiment involved multiple orientations, our subjects must have been learning to modulate sensory gain in a general sense, as opposed to optimizing gain to process a single, highly trained stimulus feature.

36.520 Dynamics of feedback-driven visual learning

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How do modality-specific visual learning and more general learning mechanisms interact in forming representations for new object categories? Prior neuroimaging studies suggest greater sensitivity to object category boundaries in prefrontal cortex (PFC) and relatively lower sensitivity to the same category boundaries in ventral cortex (Jiang et al, 2007). However, such studies have often used familiar objects, and, therefore, do not capture the full time course of learning. Here we address the role of these general learning areas of the brain (e.g., PFC) both earlier and later in learning. The relative timing of neural activity throughout the brain is informative with respect to the contributions of different brain regions as observers learn new object categories. At issue is whether the PFC requires "tuning" through ventral visual learning as a precursor to defining category bound-

aries for new objects. We used MEG to assess the neural changes concomitant with visual learning in a feedback-corrected categorization task that employed novel objects. In this task, participants learned to classify two different "families" of computer-generated "blob" stimuli as "A" or "B" (as in Krigolson et al, 2009). Participants' performance improved from chance to near-ceiling levels in the course of the single MEG session, providing behavioral and neural data that spans a much wider course of learning relative to most prior studies in this area. Beyond exploring whether ventral visual responses or PFC responses better predict both early and late visual learning, we have developed methods to improve the spatio-temporal resolution of MEG. Therefore, we are better able to associate specific brain areas with behavioral effects.

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36.521 Altered attentional modulation in visual cortex during perceptual learning

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Practising a visual task commonly results in improved performance. Often the improvement does not transfer to a new retinal location, suggesting that learning is mediated by changes occurring in early visual cortex, while neuroimaging and neurophysiological studies demonstrate that perceptual learning is associated with altered activity in visual cortex. Theoretical treatments tend to invoke neuroplasticity that refines early sensory processing. An alternative possibility is that learning involves an altered attentional state or strategy, and that the changes in early visual areas reflect locally altered attentional modulation. To test this idea, we used functional MRI to measure attention-related signals in visual cortex while participants practised an orientation-discrimination task. The two grating patches to be discriminated were presented simultaneously, one on each side of fixation. Four levels of task difficulty (fixed orientation differences) were intermixed. By recording activity in visual cortex during a preparatory period, we isolated attention-related activity in eight participants. On each trial, a cue indicating an upcoming stimulus pair and conveying the task difficulty was presented and the participant then attended the expected stimulus locations. After a variable interval, the two targets appeared for 1s and the participant responded via button presses. The experiment continued for about 40mins with short breaks. The behavioural data (percent correct trials for a given difficulty) showed a gradual improvement in performance over the session. Preparatory BOLD activity declined as learning progressed. This change was accompanied by a reduction of stimulus-evoked activity, as previously demonstrated during learning of similar tasks. Both effects were seen only at the locations of the stimuli. The change in preparatory (attention-related) activity mirrored learning, occurring most quickly for the easiest stimuli. The results suggest that spatial attention alters in some way during perceptual learning and that this may account for some of the concomitant changes seen in visual cortex.

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36.522 Increases in grey matter volume induced by perceptual learning

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Increases in cortical volume associated with practice have been reported after extensive training in complex motor tasks and following long-term cognitive training (e.g.; learning how to juggle and many years of taxi driving). Recent findings suggest plastic processes occurring also on shorter time-scales and it is an open question whether practice in merely perceptual tasks can have similar effects. In this study participants were trained on a motion-colour conjunction search task for five consecutive days (1h per day). Task difficulty was held constant throughout the training by continuously adjusting motion coherence levels. After training increases in grey matter volume were found in participants' right posterior superior temporal cortex (pSTS), an area associated with the processing of coher-

ently moving stimuli. These changes were positively correlated with performance improvements in the training task and negatively correlated with improvements in an untrained control task. These findings provide further evidence for the brain's ability to flexibly change its structure in order to deal with current task demands. Moreover, the data suggest that the well-documented effects of perceptual learning on behaviour and brain function are accompanied also by structural adjustments.

36.523 Perceptual learning and decision making in human medial frontal cortex

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The dominant view that visual perceptual learning is accompanied by changes in early sensory representations has recently been challenged. Here we tested the idea that visual perceptual learning can be accounted for by a reinforcement learning process involving changes in higher decision making areas. We trained subjects on an orientation-discrimination task involving external feedback over four days, acquiring fMRI data on the first and last day (1320 fMRI of 4620 trials). Behavioral improvements were well explained by a reinforcement-learning model in which learning leads to enhanced read-out of sensory information thereby establishing noise-robust representations of decision variables. Using a model based neuroimaging approach and support vector regression, we find stimulus orientation encoded in early visual and higher cortical regions such as lateral parietal cortex and anterior cingulate cortex (ACC). However, only activity patterns in the ACC tracked changes in decision variables during learning. These results provide strong evidence for perceptual learning related changes in higher-order areas and suggest that perceptual and reward learning are based on a common neurobiological mechanism.

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36.524 Association of perceptual learning to reduce spatial crowding with shrinkage of receptive fields

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The difficulty of identifying crowded letters can be mitigated through training (Chung, Vision Research, 2007). The underlying mechanism for such perceptual improvement has yet to be clarified. Here we report that training enhanced contrast sensitivities in association with a higher ability to identify high-contrast yet crowded letters. In our experiment, participants (n=6) were trained on an English letter identification task in which a target letter (~2°x2° in size) that was 10° away from the central fixation in the lower visual field was flanked by two other English letters of the same size and contrast with a small amount of inter-letter spacing (0.8 times the width of 'x'). In 6 days of training on this crowding task (100 trials x 10 blocks per day), the letter identification accuracy steadily improved (~15% on average) and such improvement transferred to conditions of different inter-letter spacings. More importantly, the contrast sensitivity functions were measured at locations that were also 10° away from the central fixation using 2°x2° strip patches for both upper and lower visual fields. With perceptual learning obtained after 6 days of training, significantly enhanced contrast sensitivities to a certain high spatial frequencies range were observed for the trained location (i.e., peripheral 10° in the lower visual field) but not untrained location (i.e., peripheral 10° in the upper visual field). Given that visual neurons' contrast sensitivities to harmonic stimuli are dependent upon their receptive field sizes (Wandell, Foundations of Vision, 1995), the observed enhanced sensitivities to high spatial frequencies are in accord with the hypothesis that learning to reduce crowding is associated with neurons' receptive field shrinkage at the trained location. Such receptive field plasticity may also explain why action video games (Li et al., Nature Neuroscience, 2009) among other perceptual tasks unexpectedly improve contrast sensitivities.

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36.525 Cortical reorganization in macular degeneration depends on complete loss of foveal input: A longitudinal case study

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We previously reported large-scale reorganization of visual processing (i.e., activation of “foveal” cortex by peripheral stimuli) in six individuals with extensive retinal lesions, and complete loss of foveal input from macular degeneration (MD) (Dilks et al., 2009; Baker et al., 2008; Baker et al., 2005). However, we found no evidence for such reorganization in two other MD individuals with extensive retinal lesions but some foveal sparing (Baker et al., 2007), and hypothesized that large-scale reorganization of visual processing is dependent on complete foveal loss of input from MD. Here we applied the strongest test of this hypothesis: we investigated one of the MD individuals, who originally had some foveal sparing and exhibited no reorganization, but now has lost all foveal function. We predicted that if reorganization of visual processing arises only in MD individuals with complete foveal vision loss, then we will see reorganization in this individual only after losing all foveal function, and not before. Indeed, we found reorganization in the same individual only after complete foveal vision loss. We conclude that large-scale reorganization of visual processing occurs only in the complete absence of functional foveal vision in individuals with MD.

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36.526 Training in Contrast Detection Improves Motion Perception in Amblyopia

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Many recent studies have suggested that perceptual learning could be a potential treatment for adults with amblyopia. One critical concern is whether training with one particular stimulus and task generalizes to other stimuli and tasks. Huang, Zhou & Lu (2008) examined the issue in the spatial domain and found that the improvement at the training frequency could generalize to other spatial frequencies; and the bandwidth of the improvement was much broader in amblyopic vision than in normal vision. Here, we evaluated the bandwidth of perceptual learning in amblyopic vision in the temporal domain. Previous studies on motion deficits in amblyopia (Qiu et al 2006) suggested that they are caused by spatial vision deficits. We hypothesized that training in the spatial domain could benefit motion perception. Seven anisometric and two strabismic adult amblyopes (age: 22.1±5.64) were trained in a contrast detection task using a 3×3 deg, 118 ms Gabors at their individual cutoff spatial frequency in their amblyopic eye for 10 days. Spatial contrast sensitivity functions and temporal modulation transfer functions for both motion detection and discrimination were measured for both eyes before and after training. In the amblyopic eye, training in Gabor detection near cutoff spatial frequency improved (1) contrast sensitivity by 6.6 dB across spatial frequencies, with a bandwidth of 4.4 (SE = 0.05) octaves, (2) sensitivity of motion detection and discrimination by 3.2 and 3.7 dB across temporal frequencies, respectively, with bandwidths of improvement of 3.9 (SE = 0.1) and 3.1 (SE = 0.05) octaves, and (3) visual acuity by 3.2 dB. The fellow eye also showed small amount of improvements. Control subjects who received no training showed no obvious improvement in any measurements. These results demonstrate substantial plasticity in the amblyopic visual system, and provide new empirical support for perceptual learning as a potential treatment for amblyopia.

36.527 Anatomical correlates of early vs. late symbol training

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Five monkeys were trained intensively for three years to choose between pairs of symbols using in-cage touch-screens. Two of the monkeys were trained as adults and three as juveniles. The monkeys were subsequently scanned using functional MRI while alert and passively viewing the learned symbols, faces, or unfamiliar shapes. In the juvenile-trained monkeys, regions in the occipitotemporal region, in area TE, were activated more by the learned symbols than by unfamiliar shapes. The two adult-trained, as well as another adult monkey who had not been trained on any of the sym-

bols, did not show any preferential activation by the learned compared to control shapes. These results demonstrate that intensive early experience can drive the emergence of both behavioral expertise and dedicated brain circuits for recognizing stimuli commonly used by humans but never used naturally by monkeys.

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36.528 Learning optimizes visual shape templates in the human brain

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Learning is known to improve the observers' efficiency in complex perceptual tasks and re-tune decision templates (i.e. the weight assigned to the different stimulus features based on task relevance). However, the neural mechanisms that mediate these learning-dependent changes in behavioural performance remain largely unknown. Here, we investigate whether learning alters behavioural and brain templates for visual shapes using classification image methods for the analysis of psychophysical and fMRI data. In particular, we used irregular pentagons comprised of thirty equally spaced Gaussian dots with position noise. Observers were instructed to discriminate between two types of stimuli that differed in the spatial arrangement of their shape segments. We compared behavioural performance and brain activations before and after five training sessions with stimuli presented at multiple levels of positional noise. For the analysis of the behavioural data, we used the trial-by-trial effect of noise to calculate classification images showing the stimulus parts that influence the observers' judgments. For the analysis of fMRI data, we trained a linear pattern classifier to discriminate the two types of stimuli when presented without position noise and tested the classifier's prediction on each stimulus trial. We then calculated classification images based on the prediction accuracy of the classifier in visual and parietal regions of interest. Our results showed that training improved perceptual efficiency for shape discrimination and decreased internal noise. Further, increased correlations between behavioural and brain templates with the performance of an ideal observer suggested that learning re-tunes the human templates. Interestingly, brain templates in higher occipitotemporal and posterior parietal regions rather than early visual areas improved after training, suggesting that learning tunes the representation of task-relevant features in higher visual circuits.

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Eye movements: Pursuit and following

Sunday, May 8, 2:45 - 6:30 pm

Vista Ballroom, Poster Boards 529 - 539

36.529 Spatial summation properties of the human ocular following response (OFR): dependence upon the spatial frequency of the stimulus

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We recorded initial OFRs of three human subjects when 1D vertical sine-wave gratings were subject to horizontal motion in the form of successive 1/8-wavelength steps (20 Hz temporal frequency). The gratings occupied a single horizontal strip whose height was systematically varied from 0.15° up to the full screen (36°). The strip was always centered vertically at a subject's eye level and extended the full width of the display (47°). The magnitude of the OFRs was calculated as a change in eye position over the initial open-loop period measured with respect to response onset. All gratings had a fixed contrast of 32% while their spatial frequency (SF) ranged from 0.03 to 2 cpd. Increasing the strip height led to a SF-dependent reduction in the OFR latency: the reduction was minimal (or even absent) for the highest SFs and maximal (up to 50 ms) for the lowest SFs. Since raising the height of the strip resulted not only in an increase in the total area covered by the grating, but also in a concomitant stimulus extension towards more and more peripheral portions of the visual field, we showed in a subsequent control experiment that the OFR latency reduction was due to the former but not the latter factors. The magnitude of the OFRs grew monotonically while the strip height was increased up to a certain level—the optimal

height (OH). Increasing the strip height beyond OH led to response attenuation. The OH was in the range of 1-3° for the highest SFs and 18-36° for the lowest. With very few exceptions, the OH versus SF relationship was close to linear with negative slope when plotted on a log-log scale. We will discuss if differences in the spatial distribution of relevant motion detectors and their interactions could account for the observed SF dependencies.

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36.530 Video-game training improves smooth pursuit precision

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We recently identified large individual differences in the precision of smooth pursuit eye movements (Wilmer and Nakayama, 2007), raising the question of where these differences come from and whether they can be modified through experience. Video-game playing has been shown to improve the temporal and spatial precision of attentional mechanisms (Green and Bavelier, 2003) that could contribute to pursuit precision. We therefore examined the effects of video-game training on smooth pursuit precision by training 41 participants in one of three video games for one hour a day for 7 days. We chose three video games that involved different aspects of cognition: 1) Pong, a simple sports video game involving smooth pursuit, 2) World of Padman, a first-person-shooter action game similar to those used in previous video-game training studies, and 3) World of Goo, a strategy/puzzle game that acted as a control for general game-playing effects. Results show that after Pong training, there was a significant increase in precision after the initial catch-up saccade that lasted for 200 ms, whereas for the first-person shooter game, a smaller but still significant increase in precision occurred 100-200 ms after the initial catch-up saccade. No significant increase in pursuit precision was found after training in the control game. Our results indicate that training in certain video games can improve smooth pursuit precision. The benefits of video-game playing are therefore not isolated to visual perception and attention, but extend to at least one visuomotor ability.

36.531 Saccadic intrusions as an index of mental workload

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This research examined the relationship between saccadic intrusions (SIs) and mental workload (MWL: the degree to which a person is engaged in thinking). SIs are similar to microsaccades, but while microsaccades are smaller than 0.2 deg of visual angle, SIs range up to 4.1 deg and are considered gaze deviations. Here we show that the frequency and magnitude of SIs are systematically related to MWL.

Eleven participants performed a gaze fixation task in which they fixated a stationary dot in the center of a monitor for about 60 s. Concurrently with the gaze fixation task, an auditory N-back task was performed to systematically vary MWL. Eye movements were recorded at 50 Hz. An algorithm automatically identified and quantified SI behavior into a SI value, which is a function of two factors; amplitudes and dwell time of the SIs per unit time.

Statistical analyses revealed that SI values increased as MWL increased. The average SI values were 0.037, 0.060, and 0.072 deg/s for the light, medium, and heavy MWL levels, respectively. A one-way ANOVA analysis found a significant result, $F(2, 30) = 39.08$, $p < .001$, and all the three follow-up pair tests (light vs. medium, medium vs. heavy, and light vs. heavy MWL levels) were significant, $p < .005$, while the most common MWL index of pupil diameter could not significantly differentiate the medium and heavy MWL levels with $p = .23$.

The results show that SIs increased as a function of MWL and that they may be a more sensitive measure of MWL than pupil diameter. In vision experiments, gaze deviations from a fixation target have been treated as outliers. However, our results suggest that gaze deviations (such as SIs) are meaningful and are related to MWL. SIs may have application as a measure of operator MWL.

36.532 Keep your eye on the ball: watching and playing sports linked to smooth pursuit precision

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Although smooth pursuit eye movements, used to keep a moving object on the fovea, were presumably beneficial to those species that evolved them, we know little of their importance in modern society. Given that some people smoothly pursue moving objects more precisely than others (Wilmer & Nakayama, 2007), if precise smooth pursuit is important for a task, individuals with more precise pursuit should perform that task better. In order to investigate the potential importance of smooth pursuit, we studied smooth pursuit eye movements in relation to a wide array of experiences ranging from sports and video game playing to reading and watching television, in a large sample of 70 participants. To measure smooth pursuit precision, participants pursued dot targets of various speeds while an eye tracker recorded their eye movements. Precision was calculated based on the correlation between dot speed and eye speed following the initial catch-up saccade (Wilmer & Nakayama, 2007). Participants also answered questions about their experiences in activities involving vision. Smooth pursuit precision did not correlate with time spent driving, reading, watching television, or using a computer. However, participants who had played sports had higher precision than those who had not played sports. Interestingly, participants who watched sports live had more precise pursuit than those who did not watch sports live, yet participants who watched sports on television had no more precise pursuit than those who did not watch sports on television. Together, these findings document a clear relationship between precise smooth pursuit and athletic involvement, raising the possibility that either precise smooth pursuit contributes to athletic involvement or athletic involvement contributes to smooth pursuit precision. Wilmer JB, Nakayama K (2007) Two distinct visual motion mechanisms for smooth pursuit: evidence from individual differences. *Neuron*, 54:987-1000.

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36.533 Microstimulation supports a causal role for the supplementary eye field in an oculomotor decision

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Neurons in the supplementary eye field (SEF) are differentially active for go and nogo conditions in an oculomotor decision task (Kim et al., 2005). However, these neurons appear to signal the rule and not the decision when the animal makes errors (Yang et al., 2010). This raises the question of whether the SEF is involved in the decision process, or whether activity here is merely correlative. In the experiments, animals performed a difficult version of our go/nogo ocular baseball task while microstimulation was applied in the attempt to influence the decision. The rule of the task is to pursue a target visually if it intersects a specific zone on the monitor, and maintain fixation if it does not. Target trajectories were chosen from a random set spaced narrowly at the corner of the zone, including one ambiguous trajectory. Microstimulation was applied on average 100-200 msec before zone intersection (duration 300 msec). Current amplitude was usually in the 50-75 μ A range, and stimulated and control trials were randomly interleaved. We found that stimulation affected the decision bias of the monkey at 12 of 27 sites. At nine sites, the animal was biased toward go decisions, and at three sites, toward nogo decisions. Surprisingly, at five other sites we found that overall performance was enhanced; the monkey performed better than control at judging both go and nogo trials. We then used Monte Carlo simulations and a bootstrap technique to test the validity of our results. The percentage of significant bias or enhancement sites produced by the bootstrap (58.2% and 51.1% respectively) was significantly smaller than in the original data (66.1% and 67.1%). Therefore, we conclude that SEF activity affects the decision, and that microstimulation here increases the weighting of the normal SEF contribution to the decision process.

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36.534 **Dynamic integration of salience and value information for smooth pursuit eye movements**

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Smooth pursuit target selection is known to be influenced by bottom-up factors, like stimulus contrast as well as by top-down factors like attention. We investigated how bottom-up salience and top-down value information interact for the dynamic guidance of smooth pursuit. Our pursuit stimulus consisted of two overlapping random-dot kinematograms (RDK) with opposite contrast polarity, which moved in directions differing by 20 deg (dot density 1 dot/deg², speed 10 deg/s). One RDK had a coherence of 40%; the coherence of the other was varied between 20 and 80% to manipulate the relative salience. In a salience baseline condition, we instructed subjects to simply pursue the stimulus. In a value condition, subjects won points for pursuing one RDK and lost points for pursuing the other RDK. The subjects were instructed to make as many points as possible, which were converted into a monetary reward at the end of the experiment. Both salience and value influenced the pursuit direction. Subjects moved more in the direction of the RDK if it was more salient and rewarded. However, the relative contributions of salience and reward changed over time. In the early phase of pursuit, subjects followed a salience-weighted average direction in both conditions. Later pursuit followed exclusively either the more salient direction in the salience condition or the rewarded direction in the value condition. In the value condition, subjects took about 450 ms until they followed the rewarded direction. Our results show that salience and value information are dynamically integrated for smooth pursuit. The integration of the top-down value information seems to be time-consuming since it is not present in the early phase of pursuit. This integration process seems to be slower for the pursuit of moving stimuli than what we had previously observed for saccadic eye movements to stationary stimuli.

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36.535 **The perceptual and cortical consequences of adaptation to smooth pursuit: an MEG study of the extra-retinal motion aftereffect**

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Adaptation to smooth pursuit produces a compelling motion aftereffect, such that a stationary test stimulus is perceived to move in the opposite direction to that of the adapting eye movement. It has been proposed that the illusory motion results from adaptation of pursuit-sensitive neurons in MT+ that receive extra-retinal eye movement signals. We sought to expand on these findings by examining the cortical substrates of this 'extra-retinal' motion aftereffect (tERMAE) using MEG, by asking whether oscillatory changes in cortical areas thought to subservise pursuit correlates with the subjective percept of the illusion. Participants (n=17) adapted to a moving target dot executing a repetitive sawtooth wave (six 2s upwards sweeps at 12°/s) in the absence of any peripheral retinal motion. This was followed by a 12s test phase (stationary fixation point), during which time participants reported the duration and direction of any illusory motion with a button press when the illusion had decayed. Results showed that 15/17 participants reported tERMAE on more than 50% of trials. Analysis of MEG data for these 15 participants revealed sustained alpha and beta suppression in FEF following eye movement adaption, with the suppression persisting for the duration of tERMAE. MT+ showed sustained alpha and beta decreases during pursuit-adaptation but only transient suppression during tERMAE. This post-adaptation suppression almost immediately returned to baseline levels. Parietal regions also showed similar spectral characteristics to MT+. We speculate that oscillatory changes in FEF could reflect the oculomotor control of fixation which in this case is likely to require the suppression of post-adaptation afternystagmus, as well as any tendency to track the illusory motion. As for the absence of any sustained MT+ responses during the illusion, it is possible that adaptation of motion-processing cortex does not necessarily manifest itself as a macroscopic oscillatory change.

36.536 **Illusory bending of a pursuit target sheds light on early direction estimation.**

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To pursue a target of interest, it must first be separated from background motion. If various sources provide information about direction, pursuit has been shown to initially average vectors, and then adopt a winner-take-all strategy. Here we show that a peripheral marker can modulate initial perceptual and pursuit integration before target direction is resolved, thus causing illusory target bending. The marker can either be used as an initial cue or provide a fixed reference point for the illusion to take place.

Subjects pursued a central target that moved outwards at 10 deg/s along a straight line for 900ms in a random direction. A 100% coherent RDK background moved within a central circular window (radius 10 deg) at the same speed in a direction that differed up to 25° from target direction. A marker consisting of a small 2-deg line was presented at the outer edge of the circular window throughout the trial. At the beginning of each trial a central fixation spot was presented together with the marker. Subjects pressed a button to initiate motion and were instructed to pursue the target with their eyes.

When the marker was aligned with target direction, observers perceived the target as moving along a straight line. However, when it was aligned with the RDK, they observed a strong illusory bend in target trajectory. Initial target direction was perceived to be closer to the marker and RDK directions. After about 200ms, the target direction seemed to bend towards its true direction. Pursuit showed a similar but smaller effect.

We present a new illusion that demonstrates how the perceived motion path of a pursuit target can be updated online as different sources of direction information from the target, background motion and peripheral cues are processed.

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36.537 **Interaction between retinal and extra retinal signals in dynamic motion integration for smooth pursuit**

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Due to the aperture problem, the initial direction of tracking responses to a translating tilted bar is biased towards the direction orthogonal to the orientation of the bar. This directional error is largely reduced over the first 200ms of tracking, consistent with the neural solution of the aperture problem (Pack & Born, 2001) and is fully corrected during the steady-state. We have proposed that pursuit dynamics reflects that of visual motion processing and can be modeled as a dynamical Bayesian inference of 2D target motion (Bogadhi et al., 2010). Such simple paradigm also offers a powerful way to explore interactions between sensory and predictive signals in controlling action (Montagnini et al., 2006). We conducted two experiments to investigate these interactions by transiently blanking the target at different moments of pursuit. First, a 450 or 1350 tilted bar translating horizontally was blanked for four different durations (0,200,400 and 800ms) during steady-state tracking. Bar orientation after reappearance changed on half of the trials. We found a marginal directional bias (compared to initial bias) when the target reappeared with no change of orientation and when target changed orientation with no transient blanking. However, there was a significant directional bias when the target reappeared with a change in orientation. Second, the target (an upright or a 450 tilted line) was blanked (duration: 200ms) on half of the trials during the initiation phase of pursuit, starting at either 100 or 180ms after pursuit onset. Line orientation was constant. We found a significant directional bias (i.e. equal to the initial bias) when 450 tilted line reappeared after a 200ms blank starting at 100ms. Such bias was marginal when the target reappeared after a 200ms blank starting at 180ms. These results suggest for a conditionally weighted mixing of retinal and extra retina signals in driving smooth pursuit.

Acknowledgement: EU Marie Curie ITN & CNRS

36.538 **Speed discrimination during optokinetic nystagmus: probing transsaccadic memory of visual motion**

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Optokinetic nystagmus (OKN) is a reflex of the eye that acts to stabilize moving images on the retina. It is characterized by a pursuit-like slow phase during which the eye tracks the moving image, and a saccade-like fast phase during which eye position is reset by a ballistic eye movement in the direction opposite the image motion. Around the time of saccades spatial perception is distorted and similar effects have been observed in association with the fast phase of OKN (Tozzi, Morrone, & Burr 2007). The aim of the current study was to evaluate to what extent the saccade-like fast phase of OKN influences perception of speed during the pursuit-like slow phase. On each trial, subjects were presented with a field of moving dots and asked to follow the motion with their eyes, i.e. OKN. After 1-2 secs, the speed of the dots was instantaneously reset to a comparison speed that was either faster or slower than the original speed. After approximately 300 more ms the dots were extinguished and the subject indicated whether the dots appeared to move faster or slower. The procedure was repeated numerous times for a range of comparison speeds and psychometric functions were fit to obtain speed discrimination thresholds. There were two conditions run in separate blocks: in the fast- and slow-phase conditions the speed was reset during the fast and slow phase, respectively. Thresholds in the fast-phase condition were generally low (mean Weber fraction approx. 5%) and were most often reduced relative to those in the slow-phase condition, suggesting that the fast phase of OKN may actually facilitate speed discrimination. Assuming that the fast phase of OKN is similar to a saccade, we conclude that transsaccadic memory of speed is very good. This result contrasts sharply with degraded transsaccadic memory for spatial position.

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36.539 **Contrast dependent biases in pattern motion perception and eye movement**

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The ocular following response (OFR) is an involuntary, short-latency eye movement evoked by the onset of rapid motion of a large visual image, and reflects neuronal activity in visual areas MT and MST. Neurons in these areas carry signals representing the true motion of 2D visual patterns (e.g. plaids - two superimposed gratings moving in different directions). When the component gratings in a plaid have different contrasts, the true motion of the pattern is unchanged but the tuning of MT neurons is shifted toward the direction of the higher contrast grating. Under these conditions, human observers' perception of motion is also biased, though less strongly. We asked whether the OFR similarly has a bias that depends on the relative contrast of plaid components.

We presented gratings and plaids moving in different directions to human observers while tracking their eye position. We fixed one component contrast at 0.4, while the other was varied in octave steps from 0.4 to 0.025. In a control condition, only one component grating with a contrast of 0.4 was presented. We presented each stimulus for 500 ms, after which subjects indicated the direction perceived. For equal contrast plaids and for gratings, the perceived motion and eye movement responses were aligned to the true motion of the stimulus. As the ratio of component contrasts increased, both eye movements and perceptual reports became more biased towards the direction of the higher contrast component. At high contrast ratios, both responses were indistinguishable from those evoked by gratings alone, even though the weaker component remained visible. At low contrast ratios, the bias in the OFR matched that of MT neurons and was greater than in perceptual reports. These differences in bias suggest that the signals contributing to perceptions and eye movements evoked by plaids are not identical.

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Motion: Local mechanisms and models

Sunday, May 8, 2:45 - 6:30 pm

Vista Ballroom, Poster Boards 540 - 556

36.540 **Sensitivity impairment for detecting color alternation along an apparent motion trajectory**

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Introduction: Beer et al. (VSS 2007) has reported that luminance modulation on multiple targets was perceptually underestimated when they were perceived as a single moving object (apparent motion). This phenomenon supports the idea that brightness signals are integrated along a motion trajectory. If this is the case similar effects may be also observed for color domain. Here we investigated whether color modulation detectability is impaired on apparent motion stimuli, and whether this impairment is surely attributed to motion perception. Methods: The stimuli were discs sequentially presented at concyclic eight locations with large spatial gaps (6.1 deg), and disc colors alternate between two colors on the L-M direction. There were two parameters to control strength of motion perception for the stimuli: stimulus onset asynchrony (SOA) and background color. The SOA changes strength of apparent motion perception (intermediate SOAs yield the strongest perception). For background color we had two conditions: the black condition, where the background color was black, and the isoluminance condition, where purple isoluminant with disc colors. Therefore motion perception was stronger for the black condition than the isoluminance condition. Color difference thresholds to detect the color alternations were measured using a 2IFC task. Results & Discussions: For the isoluminance condition, the measured sensitivity monotonically decreases as the SOA increases, as simply expected from need for iconic memory for long SOAs. By contrast, for the black condition the sensitivity was the lowest in the intermediate SOA yielding the strongest motion perception than in the other SOAs. Namely, sensitivity for detecting color modulation was impaired when motion perception was strong. These results are consistent with the idea that color signals, not only brightness signals, are integrated along an apparent motion path even when the stimulus has large spatial gaps between elements that prevent color integration in small receptive fields.

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36.541 **Color contribution to motion due to early expansive nonlinearities within the luminance pathway**

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Adding an equiluminance color grating to a similar high contrast luminance grating drifting in the same direction increases the motion response (i.e. to null the perceived motion, an opposing luminance grating needs a higher contrast). Such color contribution to motion could either be due to nonlinearities within the luminance pathway or to a color-opponent pathway (L-M) distinct from the luminance pathway (L+M). The fact that nonlinearities following the summation of the L- and M-cone contrast responses (e.g. [L+M]²) would not be sufficient to explain the substantial color contribution to motion has been taken as evidence of a color-opponent motion pathway (L-M). However, our simulations showed that expansive nonlinearities preceding the summation of the L- and M-cone contrast responses (e.g. L²+M²) would substantially increase the color contribution to motion especially when the color and luminance gratings are in phase (0 or 180 deg) compared to out of phase (90 or 270 deg). To investigate if the color contribution to motion is due to a color-opponent pathway (e.g. L-M) or to early expansive nonlinearities within the luminance pathway (e.g. L²+M²), we measured the color contribution to motion when superimposing high contrast luminance and color gratings as a function of their relative phase. We found that the color contribution to motion was about two times greater when the luminance and color gratings were in phase compared to when they were out of phase. This color-luminance phase interaction cannot be explained by a color-opponent pathway (L-M) independent of the luminance pathway (L+M). We conclude that early expansive nonlinearities within the luminance pathway substantially increase the color contribution to motion and the fact that adding a color grating to a high contrast lumi-

nance grating increases the motion response cannot be taken as evidence of a color-opponent motion pathway distinct from the luminance motion pathway.

36.542 A motion detection model based on a recurrent network

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Current motion models such as the motion energy (ME) model rely on specific, fixed neural delays between cells in the motion pathway. It is not clear whether neurons in the motion processing pathway of primates have the temporal specificity to support this assumption. Our goal was to investigate the feasibility of motion detection using a recurrent neural network without carefully tuned delays. We recorded the responses of neurons in the middle temporal (MT) area of macaques to patterns moving in the preferred or anti-preferred direction at different speeds. Next, we trained a recurrent neural network to reproduce the responses to motion in the preferred direction. The network accurately captured the temporal dynamics and speed tuning. This shows that explicit temporal delays are not needed to reproduce typical motion responses; they can be implemented with recurrent connections. We further tested the network with methods commonly used to analyze real neural data. We found that the network generalized to all moving input patterns (pattern invariance). Moreover, even though the network was trained only on motion in the preferred direction, it generalized to the anti-preferred response. Third, spike triggered covariance revealed filters similar to those in the ME model. Two excitatory filters in anti-phase had a space time slant that matched the preferred speed and direction of the output. Two inhibitory filters in anti-phase had a slant that matched the low speed anti-preferred direction. Taken together these results show that a recurrent neural network can reproduce the tuning of motion sensitive cells. When probed with standard methods, this network behaves much like the ME model, even though none of the ME stages can be mapped directly onto this architecture. In other words, the computation of the recurrent network is equivalent, but the underlying hardware is fundamentally different and, we believe, more biologically plausible.

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36.543 Direction discrimination thresholds in binocular, monocular, and dichoptic viewing: motion opponency and contrast gain control

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Purpose: The present study investigated the binocular organization of motion opponency and its relation to contrast gain control. Method: We measured luminance contrast thresholds for discriminating direction of motion for drifting Gabor patterns (target) presented on counter-phase flickering Gabor patterns (pedestal; equivalent to the superposition of two Gabors drifting in opposite directions). There were four presentation conditions. (i) Binocular: all stimuli were presented to both eyes, (ii) Monocular: all stimuli were presented to the same one eye, (iii) Dichoptic: the target was presented to one eye while the pedestal was presented to the other eye, (iv) Half-binocular: the target was presented to one eye while pedestals were presented to both eyes. In addition, we tested an increment-and-decrement condition, in which the target increased contrast for one direction of movement, but decreased it by the same amount for the opposite moving component of the pedestal. The decrement was either in the same eye as the increment, or in the other eye. Results and Discussion: Threshold-versus-pedestal-contrast (TvC) functions showed a dipper shape: thresholds decreased and then increased with pedestal contrast. At low pedestal contrasts, there was binocular summation: binocular thresholds were lower than monocular. But at high pedestal contrasts there was little difference between them. The 'dip' was smaller for dichoptic presentation than for other presentations. Thresholds were similar for monocular and half-binocular presentations at low pedestal contrasts, but half-binocular thresholds became higher and closer to dichoptic thresholds as pedestal contrast increased. The added decremental target lowered thresholds by about a factor of 2, compared with half-binocular, when the decrement was in the same eye as the increment, or the opposite eye. Several models fit to the data strongly suggest that motion opponency and contrast gain control operate at a binocular level of processing.

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36.544 Visual acuity with a motion detection target compared to Landolt Rings

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The purpose of this study was to compare visual acuity measurements with a new visual target compared to Landolt Ring visual acuity measurements. The new target, named "Dyops™" (short for Dynamic Optotypes™), is a circular ring comprised of 8 black-and-white equally sized segments. The ring spins at 40 rotations/minute and is reduced in angular size until the subject can no longer detect the rotation. The width of the ring and the size of the gaps were 1/5 the total diameter – similar to LR dimensions. Methods: Visual acuity was assessed using both methods on 34 young adult subjects screened for 20/20 vision. The 4-position LR acuity was measured by showing 5 targets at each 0.1 logMAR step to include lines that gave 100% correct and also 20% or less correct. Dyops were likewise presented in 0.1 logMAR steps. For each presentation the subject was shown 5 Dyops™ and required to identify which one was spinning. Five such presentations were made at each logMAR step. Measurements using both methods were made with no lenses, and through +1.00 and +2.00D lenses to create blur levels. Results: For each condition the probability of correct identification as function of logMAR size was determined with logistic regression. The mean slopes of Dyops and LRs were 34.9 (21.8SD) and 15.7 (8.7SD) respectively, indicating greater precision for Dyops. With no lenses, +1.00, and +2.00D lenses, Dyops™ must be enlarged .39, .24, and .09 logMAR units respectively to provide the same measurements as LRs. Considering both the precision (slope) and the logMAR difference induced by plus lenses, Dyops™ was 1.5 times as sensitive to blur changes as LRs. Conclusions: Compared to LRs, Dyops were more precise in detecting threshold acuity and more sensitive to blur, although size adjustment is needed for proper calibration.

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36.545 Pattern discrimination for moving random textures: richer stimuli are more difficult to recognize

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In order to analyze the characteristics of a rich dynamic visual environment, the visual system must integrate information collected at different scales through different spatiotemporal frequency channels. Still, it remains unclear how reliable representations of motion direction or speed are elaborated when presented with large bandwidth motion stimuli or natural statistics. Last year, we have shown that broadening the spatiotemporal frequency content of a textured pattern moving at constant speed leads to different results on a reflexive tracking task and a speed discrimination task. Larger bandwidth stimuli increase response amplitude and sensitivity of ocular following, consistently with a maximum-likelihood (ML) model of motion decoding. In contrast, larger bandwidth stimuli impair speed discrimination performance, suggesting that the perceptual system cannot take advantage of such additional, redundant information. Instead of ML, a gain control decoding mechanism can explain the drop in performance, suggesting that action and perception rely on different decoding mechanisms. To further investigate such task-dependant pooling of motion information, we measured pattern discrimination performance using these textured stimuli. Two noise patterns were presented sequentially for 250ms on a CRT monitor (1280x1024@100Hz) and covered 47° of visual angle with identical properties (mean SF, bandwidth SF, speed) except for a randomized phase spectrum. A test pattern was then presented and subjects were asked to match it with one or the other reference stimulus (ABX task). At small bandwidth and optimal mean spatial frequency (0.3cpd), subjects were able to discriminate the two patterns with high accuracy. Performance dropped to chance level as spatial frequency bandwidth increased. Increasing the mean spatial frequency decreased the overall performance. Again, these results suggest that perceptual performance is deteriorated in presence of larger information.

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36.546 Perception of ambiguous visual stimuli is flexibly modulated by associative learning

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Our perception of the world is strongly influenced by prior expectations. Accordingly, it has been shown repeatedly that experimental modification of expectations can change the appearance of visual stimuli. We asked whether perception of ambiguous visual stimuli is influenced by short-term changes in prior expectations. Thirty-four volunteers participated in a probabilistic reversal learning experiment where high or low tones were associated with leftward or rightward rotation of a subsequently presented rotating sphere stimulus. The stimulus was a random-dot kinematogram (RDK) where the direction of rotation was determined by disparity cues that yielded an unambiguous 3D appearance. The association of tones with rotation directions changed unpredictably every 16 to 32 trials in a probabilistic fashion. Randomly interspersed were RDK stimuli that lacked disparity cues and were thus ambiguous with respect to rotation direction, but indistinguishable in appearance from the unambiguous 3D stimuli. Participants were instructed to respond as fast and accurately as possible with a key press indicating the direction of rotation, and they also indicated their confidence about the reported percept after each trial. Reaction times in response to unambiguous stimuli that matched the predominant tone-rotation association in a given block were faster than responses to non-matching stimuli. Most importantly, ambiguous stimuli were more frequently perceived as rotating in the direction matching the currently predominant association. This effect was unlikely to be due to a generally lower confidence in the perception of ambiguous stimuli, as it also held when only trials rated at the highest confidence level were analysed. Across individuals, this perceptual effect of learned associations correlated with the effect on reaction times, indicating a link between the strength of associative learning and its effect on perception. These findings indicate that the perception of visual information is flexibly updated in accordance with even rapidly changing prior expectations.

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36.547 Motion transparency and spatial integration size – a modeling study

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Problem. Motion transparency is the perception of motions in more than one direction at the same spatial location, as in random dot kinematograms (RDKs) with groups of dots moving differently. Direction or speed differences between dot groups control the appearance of transparency. How do factors such as stimulus size or motion coherence (via spatial integration) affect the perception of transparency? **Methods.** We propose a computational model of visual motion detection and integration. Model V1 detects motions that are spatially integrated in model MT. We define velocity-sensitive MT cells with local on-center/off-surround selectivity in direction and speed with parameters fitted to monkey MT data (Treue et al. *Nature Neurosci* 3, 2000). Model MST integrates signals from model MT to achieve selectivity for motion patterns. Top-down signals from MST to MT and MT to V1 disambiguate and stabilize local motion estimates. Model area LIP temporally integrates motion signals and applies thresholds in order to simulate a decision. **Results.** In computer simulations of two 2AFC experiments, the model's perceptual thresholds for perception of transparency are measured. Two "bull's eye" configurations of RDKs appear to either side of a simulated "fixation point". One central disk region contains transparent motion (via an overlay of clockwise and counterclockwise rotations, surrounded by an annulus region of random flicker), the other only opaque motion, with a comparable annulus. In one set of simulations, the radii of the central disks of the bull's eyes were varied and detection rates are calculated. A second experiment varied the motion coherency of dots in disks of constant radius. Results from both experiments indicate a minimum spatial integration of motion directions and speeds is necessary to distinguish motion transparency from opaque motion by disambiguating local motions in MT and global motion patterns in MST. The model's predictions are testable by human psychophysics.

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36.548 Two forms of directional bias revealed by multistable motion stimuli

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Two superimposed sinusoidal gratings drifting in different directions can combine to appear as a single rigidly moving pattern whose motion is unambiguous. Adding a third grating can create a multistable motion stimulus. We superimposed three gratings with evenly-spaced directions of motion, 120 deg apart. Any two of these can combine and be perceived as a plaid, while the third grating is seen in isolation, moving in the opposite direction. Only one plaid is perceived at a time, and the symmetry of the stimulus suggests that each of the three possible percepts should be seen equally often. In reality, some percepts are strongly favored, so we measured and characterized this unexpected perceptual bias.

Five subjects fixated the center of a display on which we presented 'triplaid' stimuli for 500 ms; this was too brief for multistability to become evident within a single trial. Stimuli were placed at one of four randomly chosen locations symmetrically disposed around the center of gaze; after each presentation the observers reported the perceived direction of plaid motion. The triplaids were oriented so that no motion or orientation was closer than 15 deg to a cardinal. Across all locations, our observers reported near-vertical motions more often than near-horizontal, and either cardinal direction more often than oblique. They also had an independent bias to report motion toward fixation from any location.

These two forms of bias may have different origins. Bias for motion in cardinal directions could be related to similar biases in the orientation domain (e.g. Andrews & Schluppeck, 2000), but our effects seem to be tied to motion rather than orientation. The centripetal bias might reflect the action of mechanisms tuned to complex global motion patterns associated with optic flow, which could influence the integration of local motion signals.

36.549 Motion Standstill in Luminance-Modulated and Texture-Contrast-Modulated Gratings

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Motion standstill is a phenomenon in which a rapidly moving stimulus appears to be standing still. It occurs when the spatiotemporal resolution of the shape and texture perception systems exceeds that of the motion perception systems. Motion standstill has been incidentally observed in previous visual investigations but it has been studied parametrically only with isoluminant chromatic gratings and dynamic-random-dot stereo gratings-stimuli that exclusively stimulate the third-order motion system. Here we test luminance-modulated (LM) and texture-contrast-modulated (CM) gratings. LM stimuli stimulate primarily the first-order and CM stimuli primarily the second-order motion systems, although lower spatial and temporal frequencies of the CM stimuli also excite the third-order motion system. **Method:** High-contrast linearly moving LM and CM sinusoidal gratings were viewed over full ranges of spatial and temporal frequencies. The gratings were oriented +45 or -45 deg and appeared either as a 1.9 deg disk in the fovea or an 8-10 deg annulus in the periphery. Observers reported the speed, slant and motion direction of the moving grating on each trial. **Results:** For LM stimuli, motion standstill reliably occurred in both fovea and periphery: that is, motion-direction judgments were at chance, slant judgments were virtually perfect, and the grating speed was judged as zero. For CM stimuli, standstill judgments were extremely rare. The range of reliable motion standstill for foveal LM was typically 16-22 cpd, for peripheral, LM 10-13 cpd, both over the full test range of temporal frequencies (3-19 Hz). **Conclusion:** Motion standstill occurs in moving LM gratings that fall within the spatial resolution of the shape-object system but exceed the spatial resolution of the first-order motion system. The shape system extracts a single, representative stationary image from the moving display to present to consciousness.

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36.550 **The motion-induced shift in the perceived location of a grating also shifts its aftereffect**

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Motion can bias the perceived location of a stationary stimulus (Whitney & Cavanagh, 2000). However, it has not been established whether this occurs at a high-level of representation, or at early, retinotopic stages of visual processing. As coding of orientation emerges early in the visual processing stream, we tested whether motion could influence the spatial location at which orientation adaptation is seen. Specifically, we examined whether the tilt aftereffect (TAE) depends on the perceived or the retinal location of the adapting stimulus, or both. We employed the flash-drag effect to produce a shift in the perceived position of the adaptor away from its retinal location. On each trial, subjects viewed a patterned disc that oscillated clockwise and counterclockwise. Subjects adapted to a small disc containing a tilted linear grating that was flashed briefly at the moment of the rotation reversals. The flash-drag effect biased the perceived location of the grating in the direction of the disc's motion immediately following the flash, allowing dissociation between the retinal and perceived location of the adaptor. Following an interstimulus interval of 100 ms, brief test gratings were presented at one of three locations—the retinal or perceived location of the adaptor, or an equidistant control location (antiperceived). Measurements of the TAE at each location—the spatial tuning of the TAE—demonstrated that the TAE was usually strongest at the retinal location, and tended to be larger at the perceived compared to the antiperceived location. This indicates a skew in the spatial locus of the TAE in the direction of background motion. Together, our findings suggest that motion can bias the location of low-level adaptation.

36.551 **Local motion aftereffects are influenced by the global motion adaptor direction**

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'Phantom' motion aftereffects have been reported in unadapted regions following adaptation to a sectorized global motion pattern (Snowden & Milne, 1997, *Current Biology*, 7, 717-722). These are thought to reflect adaptation of higher-level detectors for global optic flow fields. Here we investigated the motion aftereffect present in local regions of a globally moving Gabor array. The array consisted of 1D Gabors that were randomly assigned local orientations and velocities consistent with a single 2D object motion. This array contained three additional uniformly oriented subsets of Gabors moving in either the global motion direction or plus-or-minus 45-degrees from this, and in one condition, an equal number of gaps where no Gabor was present. After adaptation to the globally moving array we measured the local aftereffect in each of these subsets. In Experiment 1, observers indicated the direction of the local aftereffect with a subsequently presented adjustable arrow, whereas in Experiment 2 observers judged the direction of the aftereffect relative to a concurrently presented directional probe array. In both experiments we found that the direction of the local motion aftereffect in the plus-or-minus 45-degree subsets appeared shifted toward that of the global motion aftereffect. Importantly we find no evidence of a 'phantom' local motion aftereffect when testing in gaps in the array. This suggests that rather than being mediated by detectors for optic flow, these local aftereffects reflect feedback from higher visual areas, such as MT, that acts to modify the local motion signals represented in lower visual areas, such as V1, to be more consistent with the global motion solution.

Acknowledgement: BBSRC

36.552 **An ultra-fast motion aftereffect**

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Although the speed of perceived motion in the motion aftereffect has not been extensively studied, it is generally assumed to be slower than the speed of the inducer. Here I report a dramatically faster MAE, whose speed can be 10-100 times that of the inducer. In a typical display, a field of random dots undergoes slow, coherent motion for several seconds; then, for several tens of milliseconds, the dots are re-randomized on every frame;

finally, this is immediately followed once again by slow, coherent motion. During the brief burst of visual noise, observers perceive motion in the direction opposite to the inducer, and many times its speed. As opposed to the normal MAE, observers readily and reliably report displacements, which can be used to calculate speeds. Perceived displacements generally increase with noise duration, but sublinearly, implying a deceleration of perceived motion. For noise durations over 100 ms, perceived displacements nearly saturate. For longer durations, the standard, slow MAE is perceived. Interestingly, one does not perceive the brief ultra-fast effect followed by slower motion, but slower motion alone, which therefore seems to mask the ultra-fast effect.

36.553 **Components of the curveball illusion: Independent contributions of carrier and envelope**

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Purpose: The curveball illusion (Shapiro et al., 2008) demonstrates a failure of the peripheral visual field to integrate motions without loss of location information. We were interested in examining how the two motion components independently influence the illusion strength across the visual field. Methods: We used a linear version of the illusion, with a starting point 9 deg horizontally to the right of fixation and apparent trajectories in the combinations of up/down and left/right directions. In each case, the speed of the carrier motion or that of the envelope motion was varied. Illusion strength was measured in terms of the perceived angle of the trajectory with respect to vertical. Illusion strength was also measured for the right/up direction for horizontal eccentricities from fixation (0 deg) to 15 deg for both speed variations. Results: Illusion strength was logarithmically related to speed for each component, and this relationship was very similar in all quadrants. Illusion strength also increased logarithmically over the whole range of eccentricities, with no illusion for any speed at fixation. Already at the smallest eccentricity (1 deg) there was a sizable illusion that varied with speed. Illusion strength saturated at around 15 deg eccentricity. Conclusion: The curveball illusion is well-described in terms of the component motion speeds. With constant stimulus size, illusion strength increases sharply and then saturates with increasing eccentricity. Thus, loss of location information occurs across the whole visual field, except in the very center. Shapiro A. et al. (2008). Meeting of Society of Neuroscience.

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36.554 **A flash-drag effect in random motion reveals involvement of preattentive motion processing.**

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The flash-drag effect (FDE) refers to the phenomenon in which the position of a stationary flashed object in one location appears shifted in the direction of motion in another location in the visual field. Over the past decade, it has been debated how bottom-up and top-down processes contribute to this illusion. In this study we demonstrate that randomly phase-shifting gratings can produce the FDE. In the random-motion sequence we used, the FDE inducer (a sinusoidal grating) jumped to a random phase every 125 ms and stood still until the next jump. Because this random sequence could not be tracked attentively, it was impossible for the observer to discern the jump direction at the time of the flash. By sorting the data based on the flash's onset time relative to each jump time in the random-motion sequence, we found that a large FDE with a broad temporal tuning occurred around 50 to 150 ms before the jump and that this effect was not correlated with any other jumps in the past or future. These results suggest that only two frames of apparent motion stimuli can preattentively cause the FDE with a broad temporal tuning. In the next experiment, we isolated two-frame apparent motion stimuli from the random-motion sequence we used previously, and measured the FDE by presenting the flash at various timings relative to the jump. Under this condition, observers could easily identify the direction of motion. We found the FDE again with a similar temporal tuning, but its amplitude was substantially larger than the effect originally found with the random-motion sequence. Overall, the results of this study suggest that the FDE involves preattentive motion processing but that top-down processes may also be involved in facilitation of the FDE.

36.555 **The flash-lag effect (FLE) as a biasing factor for offside determination in soccer**

Stephen R. Gabbard¹(srgabbard@gmail.com), Scott N.J. Watamaniuk¹; ¹Department of Psychology, Wright State University, Dayton OH

Leading theories of the FLE, differential neural latency and postdiction (temporally weighted spatial average), posit that a moving object's perceived position lags a temporal marker by tens of ms. Baldo (2002) suggested that the FLE might be operational on a soccer field as the Assistant Referee (AR) determines the position of a moving attacker relative to a defender, typically also moving. The temporal marker would be the observation, extrapolated anticipation, or sound of the ball being kicked by a teammate of the attacker, usually outside the foveal vision of the AR as s/he attends to the possibly offside attacker. In a study designed to simulate some of the dynamics of the offside call, four soccer referees and three non-referees judged the position of a moving blue rectangle relative to either a stationary or moving red reference rectangle at a time identified by a tone (object positions at the time of the tone were varied systematically). Trials lasted from 500 to 2000 ms and objects moved at a range of soccer-appropriate speeds. There was no fixation point and observers were free (as referees are) to pursue objects as they saw fit. Data from 30 conditions, presented randomly over several sessions, were fit with logistic functions. A 2-way repeated measures ANOVA (speed x participant group) showed significant main effects only (approach speed - $F(2,95) = 9.93, p < .0001$; participant group - $F(1,95) = 130.1, p < .0005$). Non-referees perceived the blue target rectangle to have moved further than referees. However, the effect was smaller than predicted by the typical FLE, suggesting that the FLE is unlikely to be operating on the soccer field. However, even the small position error observed would produce a robust offside call bias in soccer, which may be an adaptation to compensate for the perceptual complexity of the offside call.

36.556 **Perceptual segmentation and integration of spatially-overlapping moving features in humans and macaques**

Jennifer Gaudio¹(jlgaudio@wisc.edu), Xin Huang¹; ¹Department of Physiology, University of Wisconsin, Madison, WI 53706

To interpret visual scenes, visual systems need to selectively segment or integrate multiple moving features into distinct objects or surfaces. Previous studies have found that the perceived direction separation (DS) between two components of transparently moving random-dot stimuli is wider than the veridical DS. This perceptual "direction repulsion" is useful for motion segmentation. Here we investigate the impact of motion coherence on the segmentation and integration of spatially-overlapping moving-stimuli in both humans and rhesus macaques. Two overlapping random-dot patches moved at 5°/sec within a static aperture 7.5° across. Human subjects performed a 2AFC task to compare the DS of the moving stimuli with the angle of two static lines. Using a staircase method, we measured the perceived DS at different motion coherences and direction separations. In one experiment, the DS between two motion components was either 30° or 60°, whereas motion coherence was varied from 100% to 50%. The perceived DS progressively changed from wide to narrow as motion coherence was lowered, showing a switch from direction repulsion to attraction (i.e. smaller than the veridical DS). In the second experiment, the DS was varied from 15° to 105° while the motion coherence was either 100% or 60%. Consistent with previous findings, at 100% coherence the effect of direction repulsion depended on the DS and occurred mostly at a DS less than 90°. At low coherence, however, direction attraction was present across all direction separations used. In addition, we tested one monkey subject using the 2AFC task and the method of constant stimuli. The monkey showed high sensitivity when discriminating between transparently moving stimuli with different DS. Preliminary results indicated that the monkey's perception also changed from direction repulsion to attraction as motion coherence was reduced. These findings support the idea that motion segmentation yields to integration to overcome stimulus ambiguity.

Acknowledgement: UW-Madison SMPH, Graduate School, and Dept. of Physiology

Monday Morning Talks

Development: Disorders

Monday, May 9, 8:00 - 9:45 am

Talk Session, Royal Palm 1-3

Moderator: Zahra Hussain

41.11, 8:00 am

Perceptual learning alleviates crowding in amblyopia and the normal periphery

Zahra Hussain¹(zahra.hussain@nottingham.ac.uk), Ben Webb¹, Andrew Astle¹, Paul McGraw¹; ¹Visual Neuroscience Group, School of Psychology, University of Nottingham

Foveal acuity in amblyopia is crowded: letter identification is impaired by the presence of flankers. Here, adult amblyopic participants were trained on a flanked letter-identification task to assess whether practice reduces crowding in the fovea, and whether a reduction in crowding improves letter acuity. Participants with normal vision trained on the same task in the lower peripheral field, where there is marked crowding. The stimulus configuration comprised four flanking letters surrounding a central letter; the task was to identify the central letter. Before training, both unflanked and flanked letter acuity thresholds were measured, yielding a 'crowding ratio' (flanked/unflanked letter acuity) for three different target-flanker separations. Letter spacing was always a fixed proportion of letter size. During training (8-14 days; 450-600 trials/day), participants repeatedly performed the flanked letter-identification task at a fixed letter size, whilst target-flanker separation was varied to obtain a letter spacing threshold. After training, unflanked and flanked acuity measurements were repeated. Pre- and post-training crowding ratios of the trained groups were compared to those obtained from control groups who did not train on the task. On Day 1, we found significant crowding effects in the amblyopic fovea and in the normal lower peripheral field. For all participants, training reduced spacing thresholds across sessions. After training, we found modest improvements in unflanked letter acuity, but marked improvements in flanked letter acuity at all letter separations, both for amblyopic and normal participants. Amblyopic letter acuity improved, on average, by 0.15 logMAR. Normal participants' improvements were largely specific to the trained visual field. Crowding ratios were unchanged for the control groups. We conclude that perceptual learning alleviates crowding in the amblyopic fovea and normal peripheral visual field, and that reductions of crowding in amblyopia are accompanied by improvements in visual acuity.

Acknowledgement: European Commission

41.12, 8:15 am

Is there a 'top-down' component of crowding in peripheral and amblyopic vision?

Dennis Levi¹(dlevi@berkeley.edu), Gong-Liang Zhang², Cong Yu²; ¹University of California, Berkeley, School of Optometry, ²Beijing Normal University, Institute of Cognitive Neuroscience & Learning

Crowding represents an important bottleneck for object recognition in peripheral and amblyopic vision; however there is intense debate about the nature and locus of crowding. The present study evaluated the role of top-down influences by comparing crowding when the target and flankers were drawn either from the same set of Sloan letters, or from different sets of Sloan letters, while maintaining the same target-flanker complexity. When target and flankers are drawn from the same set of letters, crowding in normal peripheral vision is characterized by substantial flanker substitutions, in that observers frequently report a flanker, especially the outer flanker, as the target. Surprisingly, the flanker substitution effect is not evident in the central vision of most strabismic amblyopes. For these observers the rate of reporting the flankers and reporting other unused letters is similar. Crowding, and the flanker substitution effect are both greatly reduced when the target and flankers have opposite polarities. Importantly, when target and flankers are drawn from different sets of letters, crowding is markedly reduced in peripheral vision, and in the central vision of the minority of amblyopes who showed flanker substitution. Our results suggest a top-down effect on crowding which inhibits flanker sub-

stitution. This top-down effect is eliminated when the target and flankers have opposite polarities. With opposite target-flanker polarities crowding becomes equally weak regardless of whether target and flankers are from the same letter set or not.

Acknowledgement: NEI grant R01EY01728

41.13, 8:30 am

Changes in Cortical Functional Organization After Initiation of Sight in the Congenitally Blind

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Humans acquire significant visual abilities within the first few months of life. However, the neural changes accompanying these early stages of development have been hard to elucidate due to the operational difficulties of imaging very young children. By the time the children are old enough to be cooperative subjects in such studies, they have already passed major developmental milestones. We report here our results from Project Prakash, an initiative that provides an unusual opportunity to address this question by studying congenitally blind adults whose sight we were able to restore. Past work from our laboratory has behaviorally documented the significant gains in visual proficiency the congenitally blind individuals exhibit as a function of time after sight restoring surgery. These results motivate an examination of changes in brain organization after sight onset. Contrary to our prior understanding of critical periods for visual development, we find strong evidence of brain plasticity in these individuals. More specifically, using functional connectivity analyses, we find that there is a significant enhancement of cortical decorrelation as a function of time following the onset of sight. Additionally, we find marked changes in the functional specialization of the visual cortex. Regions of the brain selective for facial responses, including the fusiform facial area (FFA) and occipital facial area (OFA), develop non-monotonically after the onset of sight. These findings have important implications for our understanding of brain plasticity, the developmental progression of functional specialization and the heretofore largely theoretical notions of the development of efficient coding in the brain.

Acknowledgement: NIH, James McDonnell Foundation

41.14, 8:45 am

Pronounced visual motion deficits in developmental dyslexia associated with a specific genetic phenotype

Maria Concetta Morrone¹(concetta@in.cnr.it), Marco Cicchini², Monica Consonni^{3,4}, Francesca Bocca⁵, Sara Mascheretti³, Paola Scifo^{4,6}, Cecilia Marino⁷, Daniela Perani^{3,4,6}; ¹Department of Physiological Science, University of Pisa and IRCCS Stella Maris, Pisa, ²Institute of Neuroscience, CNR, Pisa, ³Vita-Salute San Raffaele University, Milan, ⁴Division of Neuroscience San Raffaele Scientific Institute, Milan, ⁵Department of Psychology, Ludwig-Maximilians University, München, ⁶Nuclear Medicine Department San Raffaele Scientific Institute, Milan, ⁷Molecular Biology Laboratory, Scientific Institute Eugenio Medea, Bosisio Parini

Deficits of visual motion have often been reported in developmental dyslexia, but the effects are often small and present only in a sub-population of subjects. We studied motion perception in a selective population of 10 dyslexic subjects with an alteration of the gene DCDC2 (crucial for neural migration during embryogenesis) and correlated the visual perceptual deficit with morphological changes of white matter tracts. All subjects showed a severe deficit in contrast thresholds for discriminating drift direction: 9 out of 10 patients failed to discriminate motion direction for gratings of spatial frequency higher than 2 c/deg (8 Hz, 200 ms exposure). In 6 subjects the deficit was anisotropic for motion direction: for example near normal horizontal motion thresholds but highly compromised for vertical motion. The overall average acuity for motion discrimination was around 2 c/deg (± 0.4 LU), eight times worse than typical control subjects. All patients showed normal contrast sensitivity for motion of low spatial frequencies (< 1 c/deg), and for static stimuli. Diffusion tensor imaging (DTI) revealed significant alteration of fractional anisotropy in several white matter tracts, and the amount of alteration correlated with the magnitude of the motion deficit. Of particular interest was the strong correlation with the fractional

anisotropy of the inferior longitudinal fasciculus, at two positions: one just anterior to MT+ (± 40 -20 0) and the other slightly more ventral (± 58 -40 -22). These results indicate that the observed motion deficits may reflect abnormalities of the mango-cellular pathway and of the innervation of MT+ during development. The frequently reported motion perception abnormality in dyslexia may thus result from alteration of fibre bundles associated with the specific genetic risk factors such as those reported here, rather than being characteristic of the entire dyslexia syndrome.

Acknowledgement: ERC IDEA: STANIB

41.15, 9:00 am

Color Discrimination and Preference in Autism Spectrum Disorder

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Colour obsessions and extreme affective responses to colour have been anecdotally reported in individuals with autistic spectrum disorder (ASD), while controlled studies have reported alterations in colour perception and memory (e.g. Franklin et al. 2008, 2010; Heaton et al., 2008). We examined colour preference and colour-emotion associations in ASD and typically developed (TD) populations, and related these to standard measurements of colour discrimination in the same individuals. Methods: Age- and IQ-matched ASD (n=40) and TD (n=28) young adults underwent a series of standardised tests (Neitz and Farnsworth-Munsell (F-M) tests of color discrimination; Autism Spectrum Quotient (AQ)) followed by custom-made tests of colour preference (rapid-response paired-comparison task with simple colour-block stimuli) and colour-emotion association (rapid-response association task pairing colour-blocks with cartoon emotional expressions). Results: Colour preferences in the ASD group are not significantly different from TD, and sex differences in colour preference are similar across the two groups. Colour-emotion associations are also similar across the two groups, although there are significant differences with respect to dependence on saturation and lightness, two components of colour perception. Colour discrimination is reduced in the ASD group, contrary to reports of superior performance in other sensory domains. The main support for this conclusion comes from performance on the Farnsworth-Munsell color discrimination test, which requires hue sorting as well as discrimination. Significantly, we find IQ to be a predictor of performance on the F-M discrimination test, but only in the ASD population. AQ is not a predictor of performance on color discrimination tests. F-M test performance correlates negatively with the strength of color preference, but this correlation is significant only for the TD group. We conclude that altered colour discrimination in ASD is likely not to explain the occurrence of colour obsessions, and measured deficits in chromatic discrimination may be related to generic performance skills.

41.16, 9:15 am

Atypical Integration of Motion Signals in Autism

Caroline Robertson^{1,2}(cr419@cam.ac.uk), Cibu Thomas¹, Dwight Kravitz¹, Eunice Dixon¹, Greg Wallace¹, Alex Martin¹, Simon Baron-Cohen², Chris Baker¹; ¹Laboratory of Brain and Cognition, NIMH, National Institutes of Health, ²Autism Research Centre, University of Cambridge

Numerous studies have reported a deficit in coherent motion perception in autism spectrum conditions (ASC). Research on motion perception has identified a neural circuit in which primary motion signals represented in middle-temporal area (MT) are integrated in the banks of the lateral-intraparietal sulcus (LIP) over time towards a decision-bound. According to this model, a deficit in global motion perception should be more strongly manifest with shorter than longer stimulus durations. 36 participants (19 ASC) performed a forced-choice motion discrimination task, manually indicating the global direction of motion (left/right) of a field of dots. Stimulus duration varied between blocks (200/400/1500ms). Coherence level (4-75%) and dot direction were randomly chosen on each trial. Coherent motion perception thresholds were significantly higher in the ASC group ($p < 0.05$) only at the shortest duration (200ms). ASC and control performance at the longer durations were identical. To investigate the neural substrate of this behavioral deficit, an additional 18 participants (10 ASC) also performed an event-related fMRI version of the motion coherence task. Overall there was a reduction in the activation of the autistic MT across all coherence levels, but critically, this reduction was greater at the shorter stimulus durations. This reduction may lead to worse performance by slowing the formation of a decision variable and reducing its reliability. In conclusion, we report

a robust behavioral deficit in coherent motion perception in ASC when sensory integration time is limited. This impairment is absent at longer stimulus durations. These results point to atypical accumulation of motion signals in ASC: individuals with ASC require more evidence to reach a decision threshold than controls. Further, we have shown that this atypical accumulation is reflected in reduced activation of the autistic MT. This result may provide insight into higher-order cognitive and social deficits that rely on visual integration, such as joint attention.

Acknowledgement: NIMH Intramural Research Program, Gates-Cambridge Trust, NIH-Cambridge Fellowship

41.17, 9:30 am

No recovery of function for a specific deficit in individuating faces 40 years after a lesion in the ventral occipito-temporal cortices at age five

Xiaokun Xu¹(xiaokunx@usc.edu), Mark Lescroart², Irving Biederman^{1,2}; ¹Department of Psychology, University of Southern California, ²Neuroscience Graduate Program, University of Southern California

High-functioning acquired prosopagnosics are rare. Forty years ago at age five, MJH suffered bilateral lesions (greater on the right) to his ventral occipito-temporal cortices, including the fusiform, but his superior temporal sulci and other brain areas were spared. He is in the normal range in identifying objects and he drives (in Los Angeles!). His performance is normal, or near normal, in his discrimination of sex, expression, age, attractiveness, and direction of gaze of faces, but he shows pronounced impairment in individuating faces, on both standard tests (Benton, Cambridge) as well as a match-to-sample test in which an identical matching stimulus is paired with a distractor differing in identity. He was at chance (controls were perfect) in selecting a famous celebrity (e.g., Bill Clinton) from a non-celebrity in pairs of faces, all of whom were highly familiar to him. He can readily individuate a person on the basis of voice and shows normal, if not superior, memory for names and biographical details of the people he encounters. Somehow surprisingly, he reports good face imagery, which he evidences on a verbal feature task, e.g., Is Clint Eastwood's nose pointy? He and control subjects were scanned when viewing dynamic face and object area localizers consisting of short video clips of changing facial expressions and objects in motion. The BOLD contrast between face blocks and object blocks in MJH revealed higher activation to faces only in bilateral posterior superior temporal sulci, not in his damaged ventral temporal cortices (which contain the fusiform face area (FFA) and occipital face area (OFA) in intact subjects). These results suggest that the ventral occipito-temporal cortices are critical for face individuation—although not the perception of other face attributes—and despite the early occurrence of the lesion, that function cannot be restored through plasticity.

Acknowledgement: NSF BCS 04-20794, 05-31177, & 06-17699 to Irving Biederman

Attention: Spatial selection and modulation

Monday, May 9, 8:00 - 9:45 am

Talk Session, Royal Palm 4-5

Moderator: Preeti Verghese

41.21, 8:00 am

Attention selects informative neural populations

Preeti Verghese¹(preeti@ski.org), Yee-Joon Kim¹, Alexander Wade¹; ¹Smith Kettlewell Eye Research Institute

Motivation: For a discrimination task, the most informative neural population has the steepest tuning curve in the region of the attribute to be discriminated. For orientation discrimination, the most informative population is tilted away from the target orientation whereas for contrast discrimination, information is highest at the target orientation although the tuning is broad. Here we used psychophysics and source-imaged EEG to determine which neural population underlies contrast and orientation discrimination.

Methods: Psychophysics: Observers performed contrast or orientation discrimination on two vertical targets, located 5° to the left and right of fixation, after adapting to a full-field grating at different orientations. Source-imaged EEG: The same static targets were presented along with a cue that indicated task type (contrast or orientation) and location of the

change (left or right). Attention modulation was estimated by the response to frequency-tagged gratings within annuli that surrounded the target. To determine which neural population was selectively modulated by the task we used three different grating orientations: 0, 20 and 45°. We obtained high-density EEG data from 13 observers and estimated frequency-tagged cortical activity using a minimum norm inverse procedure combined with realistic MR-derived head models and retinotopically-mapped visual areas. Results: In the source-imaged EEG studies, attention to a spatial location clearly increased the amplitude of the response to the annulus surrounding that location. More importantly, the pattern of modulation depended on the task. For orientation discrimination, area V1 showed a sharp peak in attentional modulation in the 20° population, whereas for contrast discrimination the orientation tuning of the enhancement was more broadly tuned. Similar tuning functions for orientation and contrast discrimination, respectively, were obtained from the psychophysical adaptation studies. These findings indicate that humans attend selectively to the most informative neural population and that these populations change depending on the nature of the task.

Acknowledgement: NSF 0963914

41.22, 8:15 am

Importance of Spatial Cuing of Attention in High Precision Judgments

Richard S. Hetley¹(rhetley@uci.edu), Barbara Anne Doshier¹, Zhong-Lin Lu²; ¹Memory, Attention and Perception Laboratory (MAPL), Department of Cognitive Sciences and Institute of Mathematical Behavioral Sciences, University of California, Irvine, ²Laboratory of Brain Processes (LOBES), Dana and David Dornsife Cognitive Neuroscience Imaging Center, Departments of Psychology and Biomedical Engineering, University of Southern California

Research on spatial attention has predominately studied attention effects in low precision tasks that require discrimination between relatively dissimilar stimuli. Here, we extend tests of spatially-cued attention to a high precision task with manipulations of visual noise and perceptual workload (see Doshier & Lu, 2000). An elaborated perceptual template model (ePTM; Jeon, Lu & Doshier, 2009; Lu & Doshier, 1998; Doshier & Lu, 2000) that incorporates precision of discrimination as a factor allows the consideration of feature template tuning in the response dimension as well as previously-studied attention effects of stimulus enhancement and external noise exclusion. Orientation discrimination was tested with low ($\pm 20^\circ$) or high ($\pm 4^\circ$) precision, in either no or high external noise, in relevant set sizes of 2, 4, and 8 Gabor patches. Attention was manipulated by target precuing and simultaneous cuing. Four out of five participants showed significant attention effects in contrast psychometric functions. Consistent with prior reports, large attention effects occurred in high noise, reflecting external noise exclusion. Exclusion increased with workload and was found at all precision levels. In addition, the high precision task exhibited attention effects in the asymptote of the psychometric functions, where precued and simultaneously-cued performance ceased to converge at high contrasts. This attention effect is modeled in the ePTM with a narrowing of Gaussian-shaped orientation tuning of templates. Template narrowing decreases the response to a non-matching orientation, which has differential effects on response based on the orientation difference of the stimuli: the orientation difference in the high precision task falls on the steep region of the template and so shows the largest effect. Our results extend the understanding of spatial cuing by uncovering effects of attention on asymptotic portions of the contrast psychometric functions in high precision, in addition to the known body of attention effects in low precision.

Acknowledgement: National Institute of Mental Health Grant # R01MH81018

41.23, 8:30 am

Sustained selective attention warps perceived space: Parallel and opposing effects on attended and inhibited objects

Brandon Liverence¹(brandon.liverence@yale.edu), Brian Scholl¹; ¹Perception & Cognition Lab, Dept. of Psychology, Yale University

Selective attention influences not only which objects in a display are perceived, but also directly changes the character of how they are perceived — for example making attended objects appear larger or brighter. Here we explore the influence of sustained selective attention on where objects are perceived in relation to each other, in dynamic multi-object displays. Surprisingly, we find that sustained attention warps perceived space in a way that is object-specific: space between targets is perceptually compressed, while space between distractors is perceptually expanded. In an initial

multiple object tracking (MOT) task, observers tracked two targets among two distractors. At the end of each trial, however, observers did not click on the target objects, as in typical MOT tasks. Instead, the entire display disappeared, and subjects simply indicated the last perceived location of each object (responding for targets first, followed by distractors). Beyond global spatial compression for the display as a whole, perceived target locations were reported as closer to each other than were perceived distractor locations, in a way that could not be explained by appeal to the response order. We also found similar (and even stronger) object-specific compression effects in a task that did not involve MOT, but simply required sustained monitoring for brief probes in dynamic displays. These effects were specific to targets and distractors per se: factoring out baseline compression toward the center of the display, attended objects seemed to attract each other, while inhibited objects seemed to repel each other. These effects suggest that sustained attention warps perceived space in unexpected ways, and in a manner distinct from previously studied effects of transient attentional shifts.

41.24, 8:45 am

Encoding a spatial relationship between two objects requires selection of each object.

Lauren E. Kahn¹(laurenkahn1@gmail.com), Steven L. Franconeri¹; ¹Department of Psychology, Northwestern University

Object recognition relies on a network that codes object identities across diffuse regions of the visual field, often leading to uncertainty about the location of any given object. One solution to this problem may be to isolate a single spatial position with selective attention, allowing recovery of the object identity at that position. If so, how do we perform visual tasks that require us to compare spatial positions between objects? While such spatial relationship judgments lead to a feeling that we select multiple objects at once, we predict that they will require isolating each object over time. We tracked eye movements as participants encoded spatial relations between objects in the simplest displays involving just two objects (e.g., a green circle on the left, a red on the right). Participants compared the spatial relationship within an encoding display to a later test display. The position of the object pairs varied across the two displays, requiring encoding of relative positions within the group, rather than absolute positions on the screen. Eye movements revealed that during encoding of the relationship, participants systematically selected the two objects in a left-to-right sequence, even when they were explicitly instructed to maintain fixation. A control experiment showed that when the spatial relationships were made irrelevant by changing the task to a same-different identity judgment, the left-to-right bias disappeared. This sequential selection during relation judgments raises a new puzzle: If we must select one object at a time, how can we recover the relative spatial location between multiple objects? We speculate that the attention shift itself is used to produce the relation judgment: extracting the vector created by the shift of attention (rightward) would provide the relative location of the object that was selected second (red).

Acknowledgement: NSF

41.25, 9:00 am

Dilution and task difficulty, but not load, affect selective attention.

Yehoshua Tsal¹(jehoshua@freud.tau.ac.il), Hanna Benoni¹; ¹Psychology Department, Tel Aviv University

Load theory of attention stipulates that distinct attentional mechanisms underlie the effects of perceptual load, cognitive load, and sensory degradation on search performance. Such distinction mainly relies on the finding that increasing perceptual load reduces distractor interference whereas increasing sensory degradation or cognitive load magnifies distractor interference. We propose instead that all three manipulations simply highlight different aspects of task difficulty. We claim that the different patterns of results are due to the fact that increasing perceptual load has typically entailed the addition of neutral items capable of diluting distractor interference (Tsal & Benoni, 2010; Benoni & Tsal, 2010), whereas increasing sensory load and cognitive load has not. In the present series of experiments we jointly manipulated dilution with each type of load. We tested the effects of perceptual load, sensory degradation and memory load on distractor interference for three types of displays: low perceptual load, high perceptual load and dilution. The dilution displays contained neutral letters that were clearly distinguished from the target. Thus, these displays separated the effects of dilution and load by containing potential diluters, yet allow-

ing for a low load processing mode. Similar results were obtained for the three types of load: when dilution was controlled, increasing task difficulty increased distractor interference, but the addition of potential diluters eliminated all types of distractor interference.

Acknowledgement: Israel Science Foundation

41.26, 9:15 am

Inter-trial inhibition of spatial attention

JeeWon Ahn¹(ahn21@illinois.edu), Glyn Humphreys², Alejandro Lleras¹; ¹University of Illinois, ²University of Birmingham

What are the behavioral consequences of moving attention to a location only to find a no-go stimulus there (i.e., a stimulus that does not afford a response in the task)? To test this question, we used displays containing three go stimuli and a no-go stimulus. Participants were asked to report the identity of the target pointed at by a central cue or withhold responses when the cue pointed to the no-go stimulus. In the sequences (no-go trial followed by go trial), we examined whether moving attention to a location recently associated with no-go status would be impaired. On cue-repeated trials, the cue pointed at the same location twice in a row; on cue-changed trials, the cue pointed at two different locations across trials. RTs on cue-repeated trials were slowed compared to cue-changed trials (Experiment 1A). However, as the frequency of cue repetition increased above chance, the RT difference disappeared (Experiment 1B), indicating that participants are sensitive to the inter-trial information provided by the cue and can overcome this inter-trial bias. To rule out the contribution of Inhibition of Return to the inter-trial inhibition effect observed in Experiment 1A, we ran Experiment 2 in which only go-trials were included: unlike Experiment 1A, RTs were faster in the cue-repeated condition. Thus merely moving attention to a location on trial N-1 does not automatically make it harder to direct attention to that location on trial N. Also we tested whether our effect was inherent to the repetition of cue (rather than attending to a no-go stimulus), by replacing the no-go stimulus with an empty location. No inter-trial effect was found. Taken together, we suggest that spatial deployments of attention are marked with the success or failure of the information encountered at the attended location, thereby biasing future deployment of attention to that location.

41.27, 9:30 am

A simple feedback-based model explains the diverse effects of attention on visual responses

Thomas Miconi¹, Rufin VanRullen¹; ¹Laboratoire CerCo, CNRS, Toulouse, France

Attention modulates visual responses in diverse ways, affecting not only firing rates, but also the position, size and structure of receptive fields (shifting or extending receptive fields towards the focus of attention, both spatially and feature-wise). While recently introduced models can explain many of the effects of attention on firing rates, no current model can simultaneously account for the shifting, scaling and retuning of receptive fields reported by recent studies. Here we suggest that all these effects arise naturally from a top-down modulation, targeting the top-most areas in the hierarchy (e.g. V4 or MT), being propagated down towards lower areas through feedback connections, and interacting with short-range mutual inhibition between neighboring neurons. While feedback connections redistribute the modulation to inputs (explaining long-distance effects on receptive field position and tuning), short-range inhibition produces competition between stimuli, the range of which is automatically scaled to the size of receptive fields, in accordance with experimental results. We use a simple two-layer model, with reciprocal connections between layers and mutual inhibition between neighboring neurons, in which bottom-layer neurons are tuned to oriented edges, and top-layer neurons pool inputs from similarly-tuned neurons over a limited region of the bottom layer; attention is introduced as an excitatory modulation targeting top-layer neurons only. We show that this simple model reproduces many of the known effects of attention on visual responses, including: (i) biased competition, (ii) contrast or response gain, (iii) sharpening or scaling of tuning curves, as well as (iv) the shifting, scaling and spectral retuning of receptive fields. Our results suggest a "null model" for attentional effects in the visual cortex, in which the existence of feedback connections and short-range mutual inhibition suffices to explain all known effects of attention on neural responses.

Color and light: Mechanisms

Monday, May 9, 10:45 - 12:30 pm

Talk Session, Royal Palm 1-3

Moderator: Angela Brown

42.11, 10:45 am

Lightness of a black room seen through a veiling luminance

Alan Gilchrist¹(alan@psychology.rutgers.edu), Stephen Ivory¹; ¹Psychology Dept., Rutgers University, Newark Campus

When a full range (black to white) Mondrian is covered by a veiling luminance equal to the luminance of a white patch, observers see only light gray patches (consistent with the range compression) and no veil. But an abstract full range 3D still-life covered by a veil is seen veridically and the veil is perceived (Gilchrist & Jacobsen, 1983). A small object-filled room, viewed close-up to fill the whole visual field, in which every surface is painted white is perceived as white while the same room painted black is perceived as middle gray, a perceptual difference due to the high amplitude of luminance variations in the black room, compared with the low amplitude in the white room (Gilchrist & Jacobsen, 1984). So what happens when a black room is viewed through a veiling luminance? Will observers perceive a black room and see the veil, as predicted by the 3D display? Or will they perceive a white room, and no veil, due to the reduction in luminance amplitude? Nine observers viewed a 40 cm cubic room filled with various objects, all painted matte black and made matches using a Munsell chart. A rear-illuminated sheet of translucent acrylic was reflected in a sheet of clear glass through which the observer viewed the room. The observers perceived a white room, with an average Munsell match of 9.3, and in general did not perceive a veil. In a no-veil control condition (n=7) the room was seen as gray (6.9). Because painting a black room white does not transform the image in the same way as covering a black room with a veil, except in the gross sense of luminance amplitude, this implies that information on the exact shape of the luminance gradients is not used by the visual system.

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42.12, 11:00 am

Lightness perception in high-dynamic range contexts

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Natural images can have a very high luminance dynamic range, yet we know little about how the luminance range of a visual context influences perception. We used a high-dynamic range (HDR) display to measure how varying the luminance range of a grayscale Mondrian affects the perceived lightness of test patches. The Mondrians consisted of 5x5 arrays of square patches of fixed chromaticity. The central patch served as the test and the surrounding 24 patches provided the context. The Mondrians contained no segmentation cues indicating separate fields of illumination. The luminance ranges for the two contexts studied were 6900:1 and 31:1. The highest luminance patch was approximately the same for each context, and the surround patches were equally spaced in log-luminance. Observers matched the lightness of the central test patch to a palette of Munsell papers that was viewed in a separate illuminated chamber. Twenty-four test patch luminances were matched for each context. The range of test patch luminances spanned the range of the corresponding context. The palette matches allowed us to establish perceptual equivalence between test patch luminances across the two contexts, by equating the mean test luminance matched to each palette paper. Control experiments using uniform backgrounds indicate that our procedures reproduce salient features of classic measurements obtained with such backgrounds. The dynamic range of the context has a large effect. A 887:1 luminance test range presented in the 6900:1 context is matched to a 25:1 range presented in 31:1 context. This range compression, as well as the shape of the test-to-test mapping function, can be accounted for by models developed for lightness context effects obtained with uniform backgrounds: changing the stimulus range affects both a multiplicative gain and a subtractive offset. Much of the range compression may be attributed to a substantial change in the subtractive offset.

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42.13, 11:15 am

Mechanisms of the dimming and brightening after-effectsJenny Bosten¹(jbosten@ucsd.edu), Donald MacLeod¹; ¹Psychology, UC San Diego

Dimming and brightening after-effects (Anstis 1967) occur after exposure to a temporal intensity sawtooth stimulus: a subsequently presented physically steady test field appears to become dimmer or brighter, depending on the sawtooth polarity. On a dark surround, dimming is equivalent to a loss of contrast, so these after-effects may plausibly have a contrast, as well as an intensity component. To reveal any contrast component, we used adapting stimuli that dissociated contrast and intensity gradients. We had two conditions. In the first, "contrast reducing" condition, a spatial increment of declining contrast alternated with a spatial decrement, also of declining contrast. In the second condition, the contrasts increased instead. If there is a contrast component of the dimming and brightening after-effects, the contrast-reducing condition should create a dimming after-effect for a spatially decremental test field, but a brightening after-effect for a spatially incremental test field, and vice versa. Using a nulling intensity gradient to measure the magnitude of the dimming and brightening after-effects, we found no evidence of a substantial contrast component. If the after-effects are primarily ones of intensity, we might expect to find strong after-effects for S-cone isolating stimuli. However, we found no S-cone equivalent of the dimming and brightening after-effects. We conclude that the dimming and brightening after-effects are largely based on intensity changes, though this makes it surprising that there are no after-effects for S-cone isolating stimuli.

Anstis, SM (1967) "Visual Adaptation to Gradual Change of Intensity", *Science*, 155, 710-712

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42.14, 11:30 am

A low-dimensional statistical model of natural lightingYaniv Morgenstern¹(yaniv@yorku.ca), Richard F. Murray¹, Wilson S. Geisler²;¹Department of Psychology and Centre for Vision Research, York University,²Center for Perceptual Systems, University of Texas at Austin

The visual system has shape and lightness constancy over a wide range of lighting conditions. The visual system is thought to achieve constancy partially by relying on assumptions about regularities in natural lighting. Natural light is complex, but for some purposes, such as understanding shading of Lambertian objects, only low-frequency lighting patterns are relevant (Basri and Jacobs, 2001; Ramamoorthi and Hanrahan, 2001). METH-ODS: We used a multidirectional photometer to make measurements of real-world lighting. The multidirectional photometer is a 20 cm diameter aluminum sphere, mounted with 64 approximately evenly spaced photodiodes. We modelled the lighting measurements as a sum of the first three orders of spherical harmonics, and then decomposed them into the scalar, vector, and tensor representation developed by Mury, Pont, and Koenderink (2007). The latter representation gives a principled way of visualizing the light field with a scalar component that describes ambient illumination, a light vector that describes the magnitude and direction of maximum light transfer, and a tensor component that varies in shape and direction. RESULTS: We find several new regularities in natural illumination. The power of the vector and tensor components are strongly correlated. The vector and tensor components usually peak in approximately the same direction, and the difference in their directions is strongly correlated with the power of the vector. The shape of the tensor has a strong tendency to be a small subset of its theoretically possible shapes, and within this subset the shape of the tensor is strongly correlated with the power of the vector. CONCLUSIONS: Our findings reveal significant new structures in natural lighting that the visual system can rely on to solve unconstrained problems like perception of shape, reflectance, and material. We will discuss what properties of real-world scenes may be responsible for these strong regularities in natural lighting.

42.15, 11:45 am

Physiological signature of time-varying color after-imagesRobert Ennis¹(rennis250@gmail.com), Barry Lee¹, Qasim Zaidi¹; ¹Graduate Center for Vision Research, SUNY College of Optometry

At VSS 2010, we presented a new psychophysical method for measuring color afterimages. Colors of two halves of a bipartite disk were modulated sinusoidally (1/16 Hz to 2 Hz) from mid-gray to opposite ends of a color

axis and back, e.g. grey>red>grey on one half and grey>green>grey on the other. The two halves appeared identical initially, increased in difference, then decreased to no difference, then increased again in opposite phase, so that when the physical modulation returned to grey, negative afterimages were perceived: the half modulated through red appeared green and vice versa. The physical contrast between the two halves, when they appeared identical, provided a Class A measurement of the after-image magnitude. Here, we present an early neural substrate for the afterimages by measuring the responses of retinal ganglion cells (RGC) to similar stimuli. Parafoveal RGCs were shown uniform circular patches modulating towards each of the poles of the preferred axis of the cell at 1/32Hz and 1/16Hz. The responses of Parvocellular and Koniocellular RGCs vigorously tracked modulations in their preferred direction, but decreased to base-rate 1-2 sec before physical modulations returned to mid-gray, dipped below base-rate and then recovered. Cell responses to modulation in the non-preferred direction, tracked the sinusoidal dip, but the response recovered faster than the stimulus, firing was significantly above base-rate when the stimulus reached grey, and the excitation persisted for a short time. Together, the excitation and inhibition of RGCs tuned to opposite directions along a color axis provide an early neural explanation for the afterimages: cells responding vigorously at mid-grey propagate an after-image signal to subsequent stages. RGC responses to both modulation frequencies were well described by a cone-opponent subtractive adaptation with a slow time constant of 5-10 seconds. Slow neural adaptation of the RGC population thus accounted for the after-image psychophysics.

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42.16, 12:00 pm

Neural Representation of Form-Based Color Filling-In in Early Visual CortexSang Wook Hong¹(sang.w.hong@vanderbilt.edu), Frank Tong¹; ¹Department of Psychology, Vanderbilt University

Perceptual filling-in exemplifies the constructive nature of visual processing. Under special viewing conditions, surface properties such as color can readily spread to neighboring retinal locations in the absence of direct input. Recent psychophysical studies have shown that interactions between negative color images and achromatic contours can lead to multiple possible percepts of filled-in color (van Lier et al., 2009). If observers adapt to a bi-colored starburst pattern, with each spoke of the star alternately colored in red or green, then the achromatic central portion of the star can appear reddish or greenish depending on whether achromatic contours are subsequently presented to reinforce the red or green regions of the negative color afterimage. We investigated the neural bases of this form-based color filling-in by using functional magnetic resonance imaging (fMRI) in conjunction with multivariate pattern classification. In experimental runs, observers viewed filling-in displays that induced the perception of red or green in the central portion of the starburst pattern. In control runs, observers viewed weakly saturated physical colors in the central region, matching in hue to the reported filled-in percepts of red or green. We found that activity patterns throughout early visual areas V1 to V4 could reliably discriminate between the filling-in conditions that elicited an impression of red or green, even though no reliable color difference was present in the stimulus. More important, a linear classifier trained on real colors could reliably classify the filled-in color, but only in higher visual areas (areas V3 and V4). These results suggest that cortical filling-in of surface color may be accomplished at relatively later stages of visual processing, and that subjective color experiences may more closely reflect the activity found in higher extrastriate visual areas.

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42.17, 12:15 pm

How many basic color terms are there in English?Delwin Lindsey^{1,2}(lindsey.43@osu.edu), Angela Brown²; ¹Department of Psychology, Ohio State University-Mansfield, ²College of Optometry, Ohio State University

To understand the relationship between color naming and color appearance, investigators have traditionally studied color naming across languages, and have emphasized the language-to-language variability in the number of color terms in the lexicon and how they are assigned to colored

stimuli. Our previous analysis of the World Color Survey (WCS), and now of English, suggest that greater emphasis should be placed on the color naming behavior of the individual informant.

Previously, we found that the color-naming data from individual WCS informants clustered into about four universal "motifs", or characteristic combinations of color terms used to name a standard set of color samples. These motifs occur worldwide, with minor variation across individuals, across and, strikingly, within languages: most WCS languages included multiple motifs among their speakers.

Does this result apply to English? Here, we report a cluster analysis of color-naming data on 58 native English speakers, collected using instructions patterned after the WCS. Although subjects used 100 different color names among them, these represented only about 18 distinct color categories: the eleven Basic Color Terms of Berlin and Kay (1969), plus seven additional color categories. These categories were organized into at least two distinct motifs: one that included only the eleven basic terms, and one that included the seven additional terms from our glossary. Although women used more color terms than men, once the synonymous color terms were glossed to the 18 categories, equal numbers of men and women fell into each of the two motif groups.

Thus, the eleven Basic Color Terms do not adequately capture the color categorical structure of English. Rather, the diversity of color naming behavior in English, like that in the WCS, reveals differences between individuals, and regularities across individuals, not obvious from examination at the level of the language as a whole.

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Perceptual learning: Models and neural mechanisms

Monday, May 9, 10:45 - 12:30 pm

Talk Session, Royal Palm 4-5

Moderator: Alexander Petrov

42.21, 10:45 am

Perceptual Learning Leads to Hemisphere-Specific Cortical Thickening

Jascha Swisher^{1,2}(j.swisher@vanderbilt.edu), Janneke Jehee^{1,2}, Sam Ling¹, Frank Tong¹; ¹Department of Psychology and Vision Research Center, Vanderbilt University, ²Donders Centre for Cognitive Neuroimaging, Radboud University

Practicing a perceptual task, such as distinguishing small changes in the orientation of a line, often leads to improvements in performance that are highly specific to the trained stimulus. Practice with images presented in the left visual field, for instance, may not yield performance benefits when the same stimuli are shown to the right of fixation. Does this form of location-specific perceptual learning also result in structural changes within the human brain? After one month of practice discriminating differences in orientation between successively presented peripheral gratings, subjects' orientation thresholds improved from an average of 2.4 degrees prior to training to 1.2 degrees after training. Thresholds did not change significantly for stimuli presented at an untrained location in the opposite visual field, or for stimuli of an orientation orthogonal to that which was practiced. Structural MRI and cortical thickness measurements revealed a 3-5% increase in cortical thickness after training across a range of higher visual regions, including MT+ and FFA. A group random effects analysis performed across the cortical surface showed a single large region of significantly increased thickness ($p < 0.001$ clusterwise) in lateral and ventral occipital cortex. This increase in thickness was restricted to the hemisphere contralateral to the trained visual field location, with no significant effects observed in the untrained ipsilateral hemisphere. These lateralized structural changes thus show specificity resembling that of the similarly lateralized improvements in behavioral performance. These results indicate that extensive practice, even of relatively simple perceptual tasks, can trigger widespread structural changes in the adult brain over comparatively short time scales. The observed increase in cortical thickness may reflect either neuronal plasticity, such as synaptic proliferation and increased dendritic arborization, or a response to greater metabolic demands through mechanisms such as enlargement of glial cells or increased vascularization.

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42.22, 11:00 am

White matter connectivity changes between visual and higher-level cortical regions in association with perceptual learning revealed by diffusion tensor tractography

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Perceptual learning (PL) is defined as a long-term increase of performance in a visual task as a result of training and is regarded as a manifestation of plasticity in the visual system. It has been shown that some types of PL are associated with an increase of BOLD signal in the region of V1, which corresponds to the trained location (e.g., Yotsumoto et al, 2008). However, it is not clear whether structural plasticity occurs in association of PL. Neither is it whether plasticity occurs only locally within the visual cortex or globally in connectivity between the visual cortex and higher stages. To address these questions, we used diffusion tractography to identify several white matter pathways running between the visual cortex and the anterior part of the brain. Seven young adults underwent 14 daily behavioral training sessions of a texture discrimination task (TDT: Karni and Sagi, 1991). Subjects also underwent four diffusion tensor imaging scans: pre-training, after 1, 6 and 14 training sessions. Superior longitudinal fasciculus (SLF), inferior longitudinal fasciculus (ILF) and inferior occipito-frontal fasciculus (infOFF) were selected for investigation because these tracts are known to be involved in visuospatial processing, and can be reliably identified by deterministic diffusion tractography in vivo. Fractional anisotropy (FA), which represents the integrity of white matter on the identified pathways was obtained across training periods and was normalized relative to the whole brain. Behavioral results indicated that performance in TDT significantly improved by training. Results by the tractography indicated that FA values of the right infOFF and the left ILF were significantly increased after 14 training sessions. These results suggest that axonal connectivity changes occur between the visual cortex and the frontal or temporal areas, while functional activity changes occur mostly in the visual cortex, in association with PL of TDT.

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42.23, 11:15 am

Changes in white matter in young adults associated with perceptual learning

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Perceptual learning (PL) in the texture discrimination task (TDT) is specific to the presented location of the trained target (Karni & Sagi, 1991). This specificity has been supported by BOLD signal changes in the trained region of V1 (eg., Yotsumoto et al., 2008). However, little research has examined whether corresponding structural changes occur together with the functional activation changes. We used the TDT to investigate structural plasticity in visual PL. A previous, related study (Yotsumoto et al., 2009, VSS) compared white matter changes in younger and older subjects over 3 training sessions, and found changes in older subjects, but not younger subjects. Here, we tested only younger subjects over a longer period of training. Seven healthy adult subjects (22-30 years) were tested; each subject completed 14 training sessions. The subjects also underwent 4 MRI sessions at various timepoints during training: pre, post-1-day, post-6-days, and post-14-days training. We measured fractional anisotropy (FA) derived from diffusion tensor imaging (DTI). FA indexes the degree of directionality of water diffusion, and reflects the microstructural properties of white matter tracts. FA values were obtained in the white matter below the visual cortical area that retinotopically corresponded to the trained location and an untrained location. After 6 and 14 days of training, most subjects showed a relative increase in FA in the trained region compared to the untrained region. However, this increase appears to be restricted to the white matter volume underlying V2, rather than that of V1. These initial findings sug-

gest that although structural changes associated with perceptual learning occur more easily with older subjects (Yotsumoto et al, 2009), longer training leads to structural changes in the younger brain. Similarly to the results with older people, the brain regions associated with structural changes may be different from those associated with functional changes.

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42.24, 11:30 am

Multi-location Augmented Hebbian Re-Weighting Accounts for Transfer of Perceptual Learning following Double Training

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The hallmark finding in perceptual learning has been the widespread observation of specificity of learned improvements to either a retinal location or to a basic stimulus dimension. Recent literature suggests that the degree of specificity may depend on task difficulty, task precision, number of trials, the extent of initial training and double training. This complex pattern of results cries out for a coherent theoretical account. Here, we further develop a multi-location Augmented Hebbian Reweighting Model (m-AHRM) (Doshier, Jeter, Liu, & Lu, ms) to account for the specificity and transfer of perceptual learning to different spatial regions and stimuli/tasks. In the m-AHRM, several location-specific and one location-invariant representations are connected through weight structures to the decision unit, along with inputs from a bias unit and a feedback unit. The location-invariant representation receives gated inputs from all the location-specific representations. Learning at one location changes the weights between the location-specific representation for that location and the decision unit, and weights between the location-invariant representation and the decision unit. Also, the gain of the gate between the location-specific and location-invariant representation increases. We applied the m-AHRM to account for the observed transfer of perceptual learning following double training (Xiao et al, 2008). Specifically, pre-training on task T2 in location L2 allows subsequent training on a different task T1 in another location L1 to generalize to location L2, while it would not have generalized without the pre-training. The m-AHRM can reproduce the results from all three double training experiments in Xiao et al. (2008). In another study (Doshier, et al, VSS 2011), we show that the m-AHRM is also able to account for specificity results following location and/or feature changes, as well as task precision dependent specificity in perceptual learning. The m-AHRM provides a general framework to understand specificity and transfer in perceptual learning.

42.25, 11:45 am

Dissociable Perceptual Learning Mechanisms Revealed by Diffusion-Model Analysis

Alexander A. Petrov¹(apetrov@alexpetrov.com), Nicholas M. Van Horn¹, Roger Ratcliff¹; ¹Ohio State University

Performance on perceptual tasks improves with practice. Most theories address only accuracy (or, conversely, threshold) data and tacitly assume that perceptual learning is a monolithic phenomenon. The response times (RTs) provide a wealth of additional data that can be used to probe the mechanisms of perceptual learning. The current study uses the diffusion model (DM, Ratcliff, 1978; Ratcliff & McKoon, 2008) to convert error rates and RT distribution statistics into estimated parameters of various processing components. DM characterizes the process of making simple two-choice decisions. Among its many advantages is the ability to account for speed-accuracy tradeoffs and to estimate the decision and nondecision contributions to the total RT.

Method: We measured the stimulus specificity of perceptual learning of motion-direction discrimination. The stimuli were moving filtered-noise textures presented for 400 ms. 27 observers trained to discriminate small deviations from a fixed reference direction for 4 sessions with feedback, accuracy-contingent bonuses, and "slow down" messages. Session 5 tested whether the learning effects transferred to the orthogonal direction.

Results and Discussion: The d' increased by 55% on average and the mean RT decreased by 27% by the end of training. Specificity indices were $SI=0.60\pm 0.10$ for d' and 0.37 ± 0.08 for mean RT (group-level data $\pm 80\%$ bootstrap CIs). DM achieved good fits to the RT distributions for each indi-

vidual in each block. The learning curves of the DM parameters identified two distinct learning mechanisms with markedly different specificities. A stimulus-specific ($SI=0.68\pm 0.09$) increase in the drift-rate parameter indicates improved sensory input to the decision process. A stimulus-general ($SI=0.00\pm 0.08$) decrease in the nondecision-time variability parameter suggests improved timing of the decision-process onset relative to stimulus onset (which was preceded by a beep). The traditional d' analysis misses the latter effect but the diffusion-model analysis identifies it in the RT data.

42.26, 12:00 pm

Uncertainty in scene segmentation: Statistically optimal effects on learning visual representations

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A number of recent psychophysical studies have argued that human behavioral processing of sensory inputs is best captured by probabilistic computations. Due to conflicting cues, real scenes are ambiguous and support multiple hypotheses of scene interpretation, which require handling uncertainty. The effects of this inherent perceptual uncertainty have been well-characterized on immediate perceptual decisions, but the effects on learning (beyond non-specific slowing down) have not been studied. Although it is known that statistically optimal learning requires combining evidence from all alternative hypotheses weighted by their respective certainties, it is still an open question whether humans learn this way. In this study, we tested whether human observers can learn about and make inferences in situations where multiple interpretations compete for each stimulus. We used an unsupervised visual learning paradigm, in which ecologically relevant but conflicting cues gave rise to alternative hypotheses as to how unknown complex multi-shape visual scenes should be segmented. The strength of conflicting segmentation cues, "high-level" statistically learned chunks and "low-level" grouping features of the input based on connectedness, were systematically manipulated in a series of experiments, and human performance was compared to Bayesian model averaging. We found that humans weighted and combined alternative hypotheses of scene description according to their reliability, demonstrating an optimal treatment of uncertainty in learning. These results capture not only the way adults learn to segment new visual scenes, but also the qualitative shift in learning performance from 8-month-old infants to adults. Our results suggest that perceptual learning models based on point estimates, which instead of model averaging evaluate a single hypothesis with the "best explanatory power" only, are not sufficient for characterizing human visual learning of complex sensory inputs.

Acknowledgement: Swartz Foundation, NIH, Wellcome Trust, EU-FP7-Marie Curie

42.27, 12:15 pm

Does primary visual cortex operate in the universal language of modality-independent space? Insights from fMRI in the congenitally and late blind

Lora Likova¹(lora@ski.org), Ming Mei¹, Spero Nicholas¹; ¹The Smith-Kettlewell Eye Research Institute

Visual cortex activity in the blind has been shown in sensory tasks. Can it be activated in memory tasks? Our recent results in short-term blindfolded subjects imply that human primary visual cortex (V1) may operate as a modality-independent 'sketchpad' for working memory (Likova, 2010). We now raise the question of whether under long-term visual deprivation V1 is also employed in non-visual memory, in particular in congenitally blind subjects, who have never had visual stimulation to guide the development of the visual area organization. The outcome has implications for an emerging reconceptualization of the principles of brain architecture and its reorganization under sensory deprivation. Methods: We used a novel fMRI drawing paradigm in congenitally and late blind, compared with sighted and blindfolded subjects in three conditions of 20s duration, separated by 20s rest-intervals, (i) Tactile Exploration: raised-line images explored and memorized; (ii) Tactile Memory Drawing: drawing the explored image from memory; (iii) Scribble: mindless drawing movements with no memory component. Results and Conclusions: V1 was strongly activated for Tactile Memory Drawing and Tactile Exploration in these totally blind subjects. Remarkably, even in the memory task, the mapping of V1 activation largely corresponded to the angular projection of the tactile stimuli relative to the

ego-center (i.e., the effective visual angle); beyond this projective boundary, peripheral V1 signals were dramatically reduced or suppressed. The matching extent of the activation in the congenitally blind rules out vision-based explanatory mechanisms, and supports the more radical idea of V1 as an modality-independent 'sketchpad' whose mapping scales to the projective dimensions of objects explored in the peripersonal space. In higher occipital areas the differential pattern of engagement across the subject categories suggests progressive neuroplastic reorganization as visual deprivation is prolonged, in accord with an evolving cross-modal utilization of the occipital cortex to maximize its inherent functional potential.

Acknowledgement: NSF/SLC grant to LLikova

Monday Morning Posters

Perceptual organization: Shapes and objects

Monday, May 9, 8:15 am - 12:15 pm
Royal Palm 6-8, Poster Boards 301 - 318

43.301 A Comparison of Object Interpolation in Complex Motions

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The human visual system integrates fragmental inputs both in spatial and temporal domain. Palmer et al. (JEP:G, 2006) proposed that spatiotemporal interpolation of moving inputs depends on a Dynamic Visual Icon (DVI) which represents visible fragments and updates their previous positions. Unuma et al. (VSS, 2010) explored the range of motions that support object interpolation with DVI, and suggested that ecologically valid transformations which represent approaching objects in 3D space play an important role for object interpolation in ordinary environment. The present study specifically aimed to compare the sensitivities for object interpolation in complex motions including ecologically valid transformations. The effect of velocity gradients in radial motion on object interpolation was compared with those in horizontal motion. Three velocity gradients were tested in each motion condition. Participants observed the shapes of interpolated objects through multiple apertures and made two-alternative forced choice of objects. The reliability or the misalignment of edges was varied using d' as a dependent measure. The results showed a consistent effect of velocity gradients only in the radial-motion conditions, although d' in horizontal-motion conditions was higher overall than in radial-motion conditions. These results suggest higher sensitivities of human visual system for velocity gradients in ecologically valid situations, especially those in approaching and receding motion.

43.302 The influence of local orientation on shape discrimination

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Purpose: Sensitivity of human observers for discrimination of continuous or sampled radial frequency (RF) contours from a circle is in the hyperacuity range. Recent research has focused on whether the visual system predominantly relies on orientation or position information in this task. For coarsely sampled contours, orientation has been shown to be more important than position, but both are necessary for optimum performance. We investigated how modifications of local orientation information in sampled RF contours influence RF discrimination performance. **Methods:** Stimuli were composed of either 9 or 40 Gabor patches (7cpd), centred on (invisible) circular or RF 4 contours. We studied the effects of Gabor patch orientation and set-size (9 vs. 40 elements). Gabor patch orientations were either tangential (aligned with the contours), orthogonal (perpendicular to the contours), radial, parallel, randomly oriented or without orientation (7cpd bull's eyes). Discrimination thresholds for four subjects were measured in a temporal 2AFC procedure (presentation time=200ms) as the RF amplitude yielding 75% correct responses. **Results:** Thresholds for all variations on element orientation were statistically significantly ($p < 0.05$) elevated relative to tangential patterns. Random and parallel orientations resulted in the poorest performance. Discrimination performance was always better with 40 elements than with 9 elements ($p < 0.05$). **Conclusions:** With identical sample position information, orientation information consistent with the shape contour (tangential) is necessary for optimum RF discrimination performance. When Gabor orientations are parallel or random, local orientation information masks the imaginary contour defined by their positions, with worse discrimination performance than where orientation information is absent (bull's eyes). Increasing set-size results in better sampling of the contour and in performance equivalent to published data for continu-

ous contours. In summary, both position and orientation information are required for peak performance in shape discrimination but if orientation is inconsistent with the contour, orientation can mask the contour.

43.303 The persistence of global form (Part I): Stimulus inversion influences V1 fMRI activity

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The human visual system uses feedforward and feedback mechanisms to achieve and maintain the figure-ground segregation of global form. One way to study figure-ground segregation is to measure the visual persistence of global form, a type of short-term perceptual memory. Studies of persistence have shown that figure-ground segregation is maintained by the visual system for up to a few seconds following the removal of perceptual binding cues that originally led to segregation. Previous studies showed persistence-related fMRI activity in human lateral occipital cortex, but failed to show persistence-related fMRI activity in V1. If persistence were observed in V1 it would suggest that feedback from high-level visual areas influence the participation of V1 in the persistence of global form. We presented observers with outlines of faces and animals that were camouflaged until they moved; these figures were either upright or inverted. We found that both upright and inverted figures persisted for up to several seconds (measured behaviorally) after they stopped moving, but that upright figures persisted longer than inverted versions of the same stimuli. We measured persistence-related fMRI activity in several occipito-temporal regions of interest (ROIs): object-selective lateral occipital cortex (LO); face-selective occipital cortex (OFA) and the fusiform face area (FFA); and several early visual ROIs (V1, V2, V3, V4v). We observed an effect of inversion on persistence in all of our ROIs, including V1. Our findings suggest that V1 fMRI activity is influenced by the orientation of an object, even though upright and inverted versions of the same figure contain equivalent low-level stimulus information. We propose that LO and other higher-tier visual areas – including the OFA and the FFA – are part of a recurrent processing network, and that these areas facilitate visual processing in V1 via feedback. We further investigate this possibility in Part II.

43.304 The persistence of global form (Part II): Figure-specific fMRI activity in V1

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In Part I we showed persistence-related activity in V1. Was this activity localized to the retinotopic location of the figure? If so, this would suggest that higher-tier visual areas facilitate the representation of figure-specific visual information in V1. We measured fMRI activity in V1 during the visual persistence of global forms. We used global forms of three different sizes in two different experiments: an eccentricity-localizer and the main persistence experiment. The purpose of the eccentricity-localizer was to identify three retinotopic locations (ROIs) in V1, each of which would correspond to the eccentricity of the figures used in the persistence experiment. The purpose of the persistence experiment was to assess the relationship between persistence-related fMRI activity and figure size (eccentricity). We observed a sustained increase in fMRI activity (persistence) in ROIs that corresponded to the size of a given figure. Activity was reduced in the remaining two ROIs, indicating suppression. That is, we observed fMRI responses retinotopically such that increases in fMRI activity corresponding to a maintained representation of figure were delineated from background-specific decreases in fMRI activity (related to the suppression of the background). Part I suggested that higher-tier visual areas influence activity in V1 via feedback. The results presented here suggest that this influence is specific to the retinotopic location of the figure, which explains why previous studies (prior to Part I) failed to observe persistence in V1. These studies used large early visual ROIs that included both sustained

fMRI activity (persistence) and reduced fMRI activity (suppression), which combined to produce a null effect. More importantly, our present results are consistent with a recurrent processing account of figure-ground segregation that predicts which image regions are preferentially perceived as figure or as background.

43.305 Part-whole integration of 2D shapes in the hippocampus and the basal ganglia

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Subcortical structures including the hippocampus and the basal ganglia support learning and memory for specific spatial or temporal configurations of discrete items. This fMRI study (N=18) found that this role extends to online perceptual representation of configurations of local parts of 2D planar shapes. Stimuli for passive viewing consisted of one set of shape parts, which were combined differently in different epochs to create different numbers of unique whole shapes. Parts forming the top and bottom of an abstract shape were joined by a convex region to promote perceptual unitization. Stimuli were presented sequentially at 2 Hz during 16-second epochs. There were three kinds of stimulus sets: a set with 4 unique shapes created from a set of 4 parts (two unique top parts, two unique bottom parts); 4 shapes from 8 parts; and 16 shapes from 8 parts. All parts and whole shapes appeared with equal frequency in all conditions. We analyzed activation corresponding to two independent measures of part/whole sensitivity: 1) sensitivity to greater diversity of either parts or whole shapes in an epoch; 2) sensitivity to greater frequency of 1-back repetition of parts or wholes within an epoch. Greater diversity of whole shapes, but not parts, activated the hippocampus and caudate nucleus bilaterally. The body of the caudate, but not the hippocampus, was positively activated by 1-back repetition of the same part in the context of two different wholes. No such effects were seen for repetitions of whole shapes. Together these results show that 1) the hippocampus is preferentially active during passive viewing of sets of simple shapes that have component parts in common, and which are distinguished only by the specific configurations of the parts; 2) the basal ganglia network plays a role in supporting perceptual representations of objects composed of distinct subunits.

43.306 Exploring figure/ground assignment using a local method

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Most previous studies on figure/ground have employed methods that measure figure/ground (f/g) in a global, explicit manner: most commonly, subjects are simply asked which region appears to be in front. Recently Kim and Feldman (2009) proposed a method that assesses figure/ground indirectly at isolated points along a boundary. In the motion-probe method, a small spatially circumscribed motion signal is introduced at a specific point on the boundary between two differently colored regions. The subject is then asked which color appeared to move. Because the figural region "owns" the boundary - and hence the motion - the response reflects local f/g. Our current study aims to (1) expand our understanding of local f/g by investigating circumstances under which it differs from global f/g; and (2) to investigate the scope of the motion probe method, studying where it agrees or disagrees with conventional methods. We collected motion-probe responses along the boundaries of shapes in a wide variety of configurations, with a variety of conventional f/g cues present. Some displays were globally consistent, meaning the contour was assigned an apparently uniform f/g polarity along its entire length, while others were not. For globally consistent stimuli, subject responses were qualitatively equivalent to conventional measures, indicating that motion-probe responses were consistent with subjective f/g organization. But for globally inconsistent stimuli, we confirmed, as in previous studies, that the motion probe method can pick up variations in f/g assignment along a single contour that are, in principle, impossible to assess using conventional global judgments (because they involve a single judgment per contour and thus force apparent consistency). Locally inconsistent f/g assignments are a potentially revealing phenomenon, because they reflect the operation of covert competitive processes underlying the determination of f/g; and the motion probe method is a useful tool for revealing them.

43.307 The Influence of Axiality on Figure/Ground Assignment

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Many influences on figure/ground assignment have been identified, but the influence of shape is poorly understood. Here we investigate the influence of axiality - the degree to which a shape has a clearly articulated skeletal structure - by pitting axiality against a known f/g cue, symmetry. We designed displays in which a multi-part axial shape shared a common boundary with a symmetric shape (created by reflecting one side of the shape about an imaginary vertical midline). We used two methods to assess perceived f/g along the common boundary, one local, the other global. Exp. 1 used the motion probe method from Kim & Feldman (2009), in which a small motion signal is placed along the shared boundary, and the subject indicates which region moved, allowing f/g to be measured locally and independently at each point. Exp. 2 used a conventional explicit response in which subjects reported global f/g. We quantified axiality using the Bayesian MAP skeleton framework of Feldman & Singh (2006), measuring the degree to which each shape was well explained (assigned high posterior probability) by its estimated skeleton. In both experiments, we found a systematic influence of axiality on f/g responses; the skeletal posterior ratio - the degree to which one shape's skeleton explained the common boundary better than the other's - systematically influenced the assignment of border ownership. Moreover, the local posterior ratio (computed only with respect to the skeletal point responsible for a given contour point) had a measurable influence on motion probe responses collected at each boundary point in Exp. 1. We conclude that (a) more axial regions tend to own their boundaries, and hence to be perceived as figural, (b) the magnitude of the Bayesian posterior effectively captures "axiality", and (c) motion probe responses can indeed provide meaningful measurements of local figure/ground assignment.

43.308 Differential sensitivity to natural and unnatural shape and part transformations

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A fruitful method for investigating visual shape representation is to examine observers' sensitivity to different types of shape transformations. In previous work we found that, in two-part shapes, observers are more sensitive to changes in the orientation of the protruding part relative to the base shape, than they are to its translation along the base shape (Denisova et al., VSS 2009). One way to understand this result is that part articulation is a natural transformation in biological shapes, whereas part translation is not. The current study investigated the role of surface geometry by stereoscopically manipulating figure-ground assignment on the same set of contours. Observers viewed a near-vertical contour with a laterally protruding part, seen through a circular aperture. The disparity field was manipulated such that the same undulation was seen either as a protruding (positive) part or as an indentation (negative part). We measured observers' sensitivity to changes in orientation and location of the part. On each trial, observers viewed a standard shape, followed by two alternative shapes. One of the alternatives was identical to the standard; the other differed by a rotation or translation of the small part. Psychometric curves were thus derived for 2 transformations (rotation / translation) x 2 surface conditions (positive / negative part). For the orientation transformation, observers' sensitivity was on average higher for positive parts than for negative parts. However, for the location transformation, no systematic difference was observed between positive and negative parts. We note that, in the case of orientation change, the positive-part transformation occurs commonly in biological shapes, whereas the negative-part transformation does not. However, in the case of translation, both positive and negative-part transformations are unnatural. The visual system appears to be selectively tuned to shape transformations that occur naturally in biological shapes.

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43.309 Constant Curvature Parts-Based Representation of Contour Shape

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Visual representations are designed to efficiently encode visually presented information that is used to guide actions and inform decisions. Visual representations of shape must efficiently encode shape geometry, but they must also support important behaviors, like comparisons across viewpoint, recognition under partial occlusion, and judgments of similarity. Here we propose a representation of 2D contour shape based on joined segments of constant curvature. This representation can efficiently encode contour geometry while also supporting important visually guided behaviors. In three experiments we demonstrate that shapes formed from constant curvature segments are better recognized under viewing conditions that require efficient storage than similar shapes that are not formed from constant curvature segments. Together, these experiments support the idea that encoding contour shapes as joined segments of constant curvature is a strategy used by the visual system for efficiently encoding these shapes in visual working memory. We also demonstrate, however, that under conditions that do not require efficient storage, shapes formed from constant curvature segments are no easier to recognize than similar shapes that are not formed from constant curvature segments. Specifically, performance differences only arise when shapes must be stored for more than 500 ms and compared from different viewpoints. Finally, we model how a constant curvature, parts-based representation trades off between fidelity and efficiency in the encoding of contour shape.

43.310 On The Relative Effectiveness of Symmetry and Convexity as Figural Cues

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The effectiveness of convexity as a figural cue varies with context: subjects are increasingly likely to perceive convex regions as figures as the number of alternating convex and concave regions increases from 2 to 8 (57% - 89%). Peterson and Salvagio (2008) observed these context effects only when the concave regions were homogeneously colored, regardless of the heterogeneity or homogeneity of convex regions. Goldreich and Peterson (2010) modeled convexity context effects with a Bayesian observer that decided whether the displays were 2-D or 3-D assuming that (1) single objects are likely to be homogeneously colored and unlikely to change color only when occluded; (2) multiple objects can be any color; and (3) in 3-D, objects are more likely to be convex than concave. On Assumption 1 homogeneity of color is a background cue. When convex regions were homogeneously colored, however, the prior for 3-D convex objects was stronger than the background cue. We tested whether similar context effects occur with symmetry. In Exp. 1, symmetry's effectiveness as a figural cue increased as the number of alternating black and white symmetric and asymmetric regions increased from 4 to 6 (56%-68%), $p = .001$, but didn't increase farther with 8 regions (68%). Thus, the bias toward symmetric 3-D objects overcame the background cue when both symmetric and asymmetric regions were homogeneously colored. In Experiment 2, using 8-region displays, we found that the prior for symmetric 3D objects wasn't large enough to overcome the background cue when symmetric regions were homogeneously colored and asymmetric regions were not: Here, subjects saw symmetric regions as figures on only 40% of trials versus 63% of trials when asymmetric regions were homogeneously colored and symmetric regions were not, $p < .0001$. Thus, the prior is smaller for 3D symmetric objects than for 3D convex objects.

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43.311 Integration of local and global cues to reconstruct surface structure

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The computation of border-ownership (BOWN) and the reconstruction of surface structure - i.e., figure/ground assignment and the interpolation of missing contours - are essential puzzles of visual computation, in part because they epitomize the integration of local and global cues to generate

a coherent percept. Here we attempt to integrate two previous computational models and bring them to bear on this problem. In the DISC model of Kogo et al. (2010), BOWN was computed by global iterative interactions of image elements, BOWN signals were considered as a differentiated form of surface representation, and 2-D integration of BOWN signals (re-) constructed surfaces. Furthermore, the perception of illusory contours and surfaces was modeled by assuming that there are potential BOWN signals at every location in the entire space (free-space BOWNs). In a complementary fashion, Froyen et al. (2010) showed how BOWN can be estimated using Bayesian belief propagation, integrating both local cues (e.g., T-junctions and sign of curvature) and global ones (e.g., skeletal structure) in principled ways. This model included as a nonlocal factor skeletal (medial-axis) structure, under the hypothesis that the medial structure that explains the border best draws its ownership. Here we combine these approaches to yield estimates of surface structure throughout the image, including both the interiors of surfaces as well as all points along the boundaries. We integrate the idea of free-space BOWN to include the computation of illusory contours into the Bayesian framework. Within this dynamic generative model, free-space BOWN signals are estimated by recurrent feedback from higher-level medial structure. Two processes alternate iteratively to estimate local free-space BOWN: (1) skeletal structure is estimated from the BOWN signals and (2) skeletal structure generates new free-space BOWN signals. This process eventually converges onto estimates that are in line with human perception.

43.312 Correspondence in apparent motion: Features don't like to travel far

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The "correspondence problem" refers to the task of maintaining object identity as the objects or the eyes move. Overall, the many studies using ambiguous motion displays (e.g., the motion quartet) find little or no influence of features (e.g., color or size) in resolving correspondence but a dominant influence of spatial and temporal proximity. In contrast, recent studies using the Ternus display show that feature information can play an important role in solving the correspondence problem (e.g., Hein & Moore, VSS 2009, VSS 2010). We investigated this conflict between the two paradigms by looking at the effect of distance on the strength of the feature influence in a variation of the Ternus display. Three equally spaced discs, aligned vertically, were presented in alternation with a second set displaced vertically so that the bottom two discs of the first set line up with the top two of the other set. The discs could be perceived as moving up and down together (group motion) or with one disc "jumping" from top end to the bottom while the other discs remained stationary (element motion). We varied the horizontal offset between the two sets of discs so that they would move slightly sideways as well as up and down. We biased the percept toward element motion by matching features of surface polarity, size or spatial frequency. We found that the percept of element motion decreased as the horizontal shift increased and that the distance at which the decrease started differed for the different features. These findings suggest that feature information contributes to correspondence but only over a small spatial range. This limited range explains why the Ternus display shows a feature effect - the central discs are typically spatially superimposed - whereas other apparent motion displays use large spatial offsets and show little or no feature effects.

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43.313 Object Surface Completion: Filling-Out by Incremental Filling-In

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In two experiments we used bilateral and unilateral backward masking to investigate the time course of a rectangular target's surface completion. Our results show in both the bilateral and unilateral masking conditions that surface completion proceeds as a "filling out" from the interior middle region of the target toward its edges. Both masking procedures yield similar estimates of a filling-out speed at about 25 deg/sec in retinal coordinates, a value about 20% of the filling-in speed reported in prior studies. Moreover, using the relationship (based on human cortical magnification estimates) between retinal distance and cortical distance, our results show

that the cortical filling-out speed proceeds at about 0.4 m/sec. Using Watt's MIRAGE model, we offer an explanation of our results in terms of a spatio-temporal process of filling-out by progressive filling-in.

43.314 The Binding Ring Illusion: Misperceived size constrains models of size perception

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Our percept of an object's size arises from the integration of multiple sources of visual information including retinal size, perceived distance and relative size. This constructive process is revealed through a number of classic size illusions such as the Mueller-Lyer Illusion, the Ebbinghaus Illusion and others illustrating size constancy. Here we present a novel size illusion that we have named the Binding Ring Illusion that is not easily explained by existing models of size perception. The perceived radius of a circular array of elements is underestimated when superimposed by a circular contour – a binding ring. Here we characterized the stimulus conditions that lead to the illusion. Methods: Using the method of constant stimuli, observers were presented with two arrays (one with a binding ring and one without), and asked to indicate which was perceived to be larger. Results: The results of experiment 1 demonstrate the influence of the binding ring is quite robust and consistent across subjects. In experiments 2 and 3, we investigated the possible role of occlusion and depth ordering of the binding ring. In these latter experiments, the binding ring was either occluded by the array elements or only visible through the interiors of the array elements (as if viewed through a hole). Paradoxically, the results of experiments 2 and 3 suggest that the size distortion depends upon the entire binding ring being visible and superimposed on the array and not upon depth ordering cues, as is the case with other size illusions. Conclusion: The Binding Ring Illusion demonstrates that under certain circumstances perceived size may be computed prior to perceived distance.

43.315 Reevaluating whether attention is drawn to figures

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Is attention automatically drawn to figures? Some evidence suggests "yes." Nelson and Palmer (2007) reported faster responses for targets shown on the familiar vs. complementary side of bipartite, equal area displays, although targets were equiprobable on both sides. Familiarity is a figural cue; hence they concluded that attention is automatically drawn to figures. We investigated whether similar results were obtained with the figural cue of convexity (Mojica, et al., VSS2009). In 3 experiments we found no evidence that attention is automatically drawn to convexity, or to convex regions perceived as figures: Subjects were equally fast to discriminate targets presented on the convex side of a bipartite display, $p > 0.99$. Our displays were smaller than Nelson & Palmer's ($3^\circ \times 6^\circ$ vs. $18^\circ \times 20^\circ$). Were their results due to familiarity, per se, or to the strategic allocation of attention to familiar regions when displays were large and targets far from fixation? This year, we used 16 small ($5.3^\circ \times 5.5^\circ$), bipartite equal-area displays depicting a familiar shape on one side. Each display appeared twice, once upright, once inverted. Participant's primary task was to report whether a target shown equiprobably on each side was an "X" or a "Y." For upright and inverted displays, response latency was not different for targets appearing on the familiar versus the complementary side, all $ps > 0.11$. Participants also reported figure-ground perception. Subjects perceived the familiar region as the figure more often than chance in the upright displays, $p < 0.0001$, yet we found no evidence that attention was automatically drawn to the figural side. We suggest that the previous results may have been due to the strategic allocation of attention when targets are located far from fixation. Other evidence that attention is automatically allocated to figures may also reflect strategic attentional deployment.

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43.316 Differences in the Role of Context on Polar and Translational Glass Patterns

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Thresholds for stimuli that rely upon activity from early visual mechanisms can be modulated by contextual information. In the orientation domain, for example, thresholds for targets that are surrounded by parallel elements are typically higher than thresholds for targets that are surrounded by orthogonal or grey surrounds. These behavioural results are thought

to reflect inhibitory interactions between neurons that are tuned to similar stimulus properties. In the current study, we evaluated whether the same contextual effects would be observed with stimuli that probe mid-level form mechanisms. Coherence thresholds were evaluated for polar (ie., concentric and radial) and translational (ie., vertical and horizontal) Glass stimuli using the method of constant stimuli and a 2IFC paradigm. Baseline coherence thresholds were first determined for stimuli with no surround (radius = 1.25 σ ; dot density = 12%), where subjects discriminated Glass patterns from noise with no coherent form. Thresholds were then determined when stimuli were surrounded by a pattern that was either the same as, or different from, the central pattern. With translational stimuli, thresholds for all 4 subjects were higher with the same surround than they were with a different surround. With polar stimuli, thresholds for 3 subjects were lower with the same surround than they were with a different surround (for one subject, polar thresholds did not differ between the 2 surround conditions). This demonstrates that the role of the surround on translational form perception is qualitatively different from the role of the surround on polar form perception for the stimulus parameters we have chosen here. We propose that this difference can be explained in terms of differences in the extent of spatial pooling that occurs between early vs. mid-level visual neural mechanisms.

43.317 Object-based warping: Distribution of distortions over an object's surface and independence of shape

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Distances between points within the surface of an object are illusorily expanded compared to equivalent distances outside of an object, an effect we have termed "object-based warping" (Vickery & Chun, 2010, Psychological Science). Further insights into the causes of this distortion would benefit from examining variation of object-based warping over the entire object's surface, and across different enclosing shapes. To measure warping, we asked participants to adjust the spacing between two adjustment dots to match the spacing between two fixed reference dots. We compared judgments when the reference dots were placed in and around objects to when they were presented in the absence of objects. Prior studies used points symmetrically distributed around the object mid-line. Here, we examined variation over a vertical rectangular object's surface by considering seven equally-spaced points along its vertical midline from the top edge to the bottom edge. On each trial, dots were presented at two of these points. Every possible position pair was probed. Warping effects were observed for all interior segments tested, such that estimated spacing was 5-12% greater with than without an object. Segments with at least one point at the object's boundary showed no significant warping, and significantly weaker warping than non-boundary segments for every spacing, implying that object-based warping depends on surface enclosure. For distorted interior segments, there was no systematic variation due to segment size, other than a tendency to report the smallest distortions for small segments relative to baseline (5%, relative to 9-13% distortions for larger segments). Across multiple additional experiments, we observed object-based warping on variable shapes (rectangles, squares, circles, triangles), as well as on the surface of three-dimensional objects. Object-based warping is uniform across the interior of an object and extends to different shapes and volumes, suggesting that warping is a generalizable consequence of object-hood.

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43.318 What's the "Point"? Assessing the Effectiveness of Stimuli that Indicate Direction

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Previous research by Attneave, Palmer, and others has examined why stimuli such as triangles are seen to point in one direction rather than another, but little research has been done on what makes a given stimulus point at all, i.e., convey directional information. Arrows, Vs and triangles are often used to indicate direction, but it is not apparent why they are more commonly used than are other, similar, stimuli such as checkmarks, Ts, Us, or Ys. Arrows, Vs, triangles, Ts, Ys and checkmarks all contain V-intersections, where the vertex could define pointing direction. Additionally, an arrow is symmetric whereas a checkmark is asymmetric; thus, symmetry along the axis in the direction of pointing may be important. The present work is a first attempt at a systematic catalog of perceptual properties of

shapes as they relate to pointing strength and direction. Arrow-like shapes were systematically manipulated along several dimensions, including the angle of the chevron's vertex, the ratio of the width of the chevron to the length of its line, and the position of the chevron along the line. Participants judged perceived pointing strength and direction, and they also performed speeded navigation tasks requiring use of these pointers. The results show large differences in the effectiveness of different pointers in both judgment and performance tasks. In addition to providing insights into the perception of pointing, the present work may be valuable for the design of effective directional indicators for use on roadway signs and computer navigation systems.

Attention: Temporal

Monday, May 9, 8:15 am - 12:15 pm

Royal Palm 6-8, Poster Boards 319 - 329

43.319 Distractor Suppression During the Attentional Blink: Behavioral Evidence for Flexible Selection

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A long line of empirical evidence suggests that all items presented during the attentional blink (AB) are processed to a semantic, or post-perceptual, level. This evidence has led to the common theoretical assumption that the level of selection during the AB is fixed at a post-perceptual stage. However, recent evidence suggests that first target (T1) task difficulty modulates post-perceptual processing during the AB – a finding that suggests that the level of selection during the AB is flexible. These recent studies have used either spatial manipulations or task switches between T1 and the second target (T2) thereby raising the possibility that the influence of T1-difficulty on post-perceptual processing during the AB might be determined solely by these factors rather than due to T1-difficulty. To test whether the influence of T1-difficulty on post-perceptual processing during the AB can occur in the absence of either of these factors, 61 participants performed a standard RSVP task in which both the T1 and T2 tasks involved identifying a red or green letter in a stream of white distractors. Critically, T1-task difficulty was manipulated and the influence of T1-difficulty on the processing of subsequent information was assessed by inserting a white priming distractor with the same identity as the T2 on half of the trials. Replicating previous work (Dux & Marois, 2008), T2 accuracy was higher during the AB when it was preceded by a prime than when it was not. Importantly, under conditions of high T1-difficulty the influence of the prime was decreased. These results suggest that T1-difficulty is an important factor that determines if information presented during the AB is processed to a post-perceptual level. Moreover, these results support the notion that the level of processing during the AB is not fixed, but rather is flexible.

43.320 The attentional blink impairs saccade production

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When two targets occur in rapid succession, task-related processing of the first target often causes a marked impairment on task performance for the second target. This phenomenon is known as the attentional blink. Previous research has suggested that when the targets are in different spatial locations, this deficit is partially explained by a delay in the ability to covertly shift attention to the second target (T2) location after the first target (T1) is detected. The current work investigates how the attentional blink influences the overt allocation of attention by measuring saccadic eye movements. Our task required that participants first detect T1 in a central stream of letters and then make a saccadic eye movement to a peripheral T2 target. A control condition in which the T1 target was present but irrelevant was also included. Critically, the results showed that saccadic latency relative to the appearance of the T2 target was significantly delayed when the lag between the T1 and T2 targets was short. However, this period of impaired performance was considerably shorter than the typical attentional blink, suggesting that the slowing of eye movements solely reflects the spatial attention component of the blink.

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43.321 Rational expectations about object transitions account for the attentional blink and repetition blindness

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People fail to individuate two similar objects separated by a brief interval (repetition blindness), and miss the second of two different objects separated by 300 msec (attentional blink). Might these phenomena arise from rational expectations about the rate at which new objects appear? A prior over object transitions can be derived from many world distributions; I use intersaccadic dwell times (lognormal with mean of 100 msec and SD of 3 dB). Conditioned on seeing an object at time t , this prior on object transition yields two hazard functions: the probability that the same object remains in view, and the probability that a new object has appeared. These expectations yield repetition blindness when the probability of seeing the same object exceeds that of seeing a new object: <280 msec post first stimulus, and the attentional blink arises when the observer expects to be looking at neither the same object nor a new object. This model also predicts that perception of the second target will show systematic intrusions. When two objects occur in quick succession, report of the second object identity will include intrusions of distractors preceding the object; however, when the second objects occurs after a longer interval, intrusions will be biased in favor of distractors following the second object. Furthermore, the transition between early and late intrusions on the second target will coincide with a broader distribution of intrusions of all items around the second object. Both of these effects along with their time-courses were born out in previous experimental work. Altogether, a parsimonious ideal observer model based on event-transition priors, which may be derived from intersaccadic dwell times, predicts repetition blindness and attentional blink effects, as well as delay and diffusion during the attentional blink.

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43.322 Remembering the Time: Repetition of Temporal Position Facilitates Selection in RSVP

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Attention can be distributed in time as well as in space. Brain imaging studies suggest that orienting of attention in time and in space involves some common and some domain specific mechanisms (see Nobre, 2001). However, the similarities and differences between allocation of attention in time and in space have not yet been fully explored. Recently, Yashar and Lamy (2010) compared spatial visual search to search in an RSVP stream. They showed that during singleton search, target-feature activation and distractor-feature inhibition mechanisms are common to both temporal and spatial search. Post-hoc analyses of the RSVP task data revealed an additional effect: RTs were faster when on two consecutive trials the target happened to appear at the same rather than at a different temporal position. This temporal position priming (TPP) effect parallels the position priming effect found in spatial visual search (Maljkovic & Nakayama, 1996), in which repetition of target position in space speeds singleton search. This finding suggests that, as with spatial positions, temporal positions can be represented and encoded in implicit short-term memory, and that this encoded representation can guide the allocation of attention in time. In the present study we establish the existence of TPP and examine the similarities and differences between priming of position in space and priming of position in time. We show that TPP is eliminated when the target position in time is predictable. We also show that TPP is observed whether or not the target feature that is relevant for selection is constant or changes unpredictably. We conclude that (1) encoding of temporal position is automatic, (2) traces of the temporal position of the target on the previous trial facilitates search when the target position in time is uncertain, and (3) temporal position priming speeds processes related to engaging attention in target.

43.323 Updating temporal representations

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Humans maintain internal models to generate expectations and predictions about the external world. Critical for the reliance on such models is that they be updated to reflect salient environmental changes. One possible signal of environmental change is that incoming sensory information and mental model predictions mismatch. Deficits in updating spatial representations have been well demonstrated following brain injury, especially right parietal injury. Here we explore the ability of healthy individuals to generate

and update temporal representations. An image of a red square was briefly displayed to experimental participants ($n = 20$). After each presentation, participants were asked to predict if the next presentation would be longer or shorter. Presentation durations were randomly chosen from 400 to 700 msec in duration (step size 50 ms). Following a period of guessing behaviour (approx. 50 trials), accuracies improved (range 56% to 71%) confirming that participants can form a mental model for these short time intervals. To evaluate if participants can update this representation when presented with a covert salient environmental shift, we shifted the range of temporal durations to 600 - 900 msec (50 msec steps) without informing participants. Confirming the ability to detect this slight shift, after a period of transition, participants shifted their behaviour for the stimulus presentation durations that were common to both conditions (600, 650, and 700 msec) from "next trial shorter" to "next trial longer." However, performance was not as accurate, and did not change as quickly, for the second set of durations as it had for the first set of durations. In summary, we describe a task for the assessment of updating temporal representations of subsecond durations and show the effect of history on mismatch detection.

43.324 Temporally structured and symbolic cues operate via different mechanisms: Psychophysical and chronometric evidence.

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It has been suggested that visual attention may be allocated at points in time by either a stochastic clock or coupled oscillator. Behavioral data and functional neuroimaging have hinted that both mechanisms may operate in parallel, but evidence has been ambiguous. To further distinguish between possible mechanisms of dynamic visual attention, 11 observers were given a perceptually difficult visual motion direction discrimination task in three cueing conditions: alerting, isochronous countdown, and symbolic cueing. In the alerting condition, a single cue alerted participants that the target was about to occur. In the isochronous countdown condition, multiple flashes counted down to the target onset, affording entrainment of a coupled oscillator mechanism, timing by a stochastic clock, or both. In the symbolic cueing condition, a single letter cued the time of target onset (one of two possible intervals), precluding entrainment of a coupled oscillator but affording an unambiguous signal for a stochastic timer. The stimuli were random dot cinematographs moving with net motion directions that differed by 45°, with variable amounts of noise. In addition to analyzing response latency and accuracy, a diffusion model of perceptual decisions was used to estimate the rate of information accumulation, boundary separation, and non-decision time. The isochronous countdown had little effect on latency or accuracy, but observers were slower and more accurate after a symbolic cue, indicating that the different cueing conditions induced a speed-accuracy tradeoff. Diffusion model analysis indicated that symbolic cues increased the boundary separation of the decision process and non-decision time, consistent with the idea that participants were slower because they strategically accumulated more information before committing to a response. The isochronous countdown, in contrast, had little effect on the perceptual decision process. The results contradict the idea that temporally structured cues and symbolic cues operate via the same mechanism.

43.325 Detecting sequence disruptions within events is not automatic.

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To understand event perception, we must determine how people process the sequence of actions that make up an event. Event Segmentation Theory (Zacks et al, 2007) proposes that event segmentation and understanding is driven by a continuous cycle of perceptual predictions and error detection. According to this model, an error detection mechanism compares predictions with perceptual input. Increases in prediction error lead to an updating of event models, causing an event boundary. However, previous research may have overemphasized the importance of ongoing perceptual prediction in event perception. This series of experiments tested whether individuals use such moment-to-moment predictions in real time. Participants viewed videos (consisting of a series of eight to fourteen different shots, with each shot lasting an average of 820 ms) of actors performing everyday events that either did or did not contain a misordered action (for example, a shot of an object being used before a shot of it being picked up). When instructed to look for misorderings, participants' detection of

misordered events was low, and performance was close to floor when an incidental detection paradigm was used. Additionally, an interference task significantly lowered detection of misordered events, nearly to floor levels. Finally, participants were almost always able to detect the misordered events themselves (as opposed to detecting the fact that they were out of order), suggesting that error detection may not be an automatic process as previously argued. Combined, these results suggest that participants were able to clearly perceive individual actions within the misordered events, while perceiving the fact that they were misordered was far more difficult. These data suggest that automatic moment-to-moment predictions are not always the basis for understanding events.

43.326 Lateralized Temporal Parietal Junction (TPJ) activity during temporal order judgment tasks

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Introduction. Damage to the temporal parietal junction is commonly linked to deficiencies in spatial attention, particularly in contralateral space. Other studies, however, have shown patients with unilateral parietal damage to have bilateral deficits in attention, particularly for those tasks that measure the temporal aspects of attention (Battelli et al., 2003; Husain and Rorden, 2003). This study seeks to measure the neural correlates of temporal attention using fMRI. Methods. In a blocked fMRI design, subjects viewed a quartet of disks (2 in each hemifield symmetric around the midline) flickering black and white for 1000 msec at a frequency of 8 Hz, with one disk in opposite phase relative to the other three. For 350 msec before and after the flicker, the disks consisted of stationary high contrast texture, with one disk having lower contrast than the others. Subjects were instructed to attend to the disks in either the left or right hemifield, and, in the temporal order task, report whether the disks were in or out of phase. In the texture task the subjects were instructed to report whether the disks in the attended hemifield had equivalent contrast. Results. GLM analysis on the individual subjects revealed a main effect of task in the TPJ for six of the ten subjects, with three additional subjects showing unilateral right TPJ activation during the temporal order judgments. A group analysis measuring for hemifield effects found stronger contralateral TPJ activation during the temporal order judgments as compared to the texture task. Conclusions. Our findings support the notion that the TPJ is involved in selectively attending to temporal features of visual stimuli. Our group analysis also suggests a bias towards the contralateral TPJ when these judgments are made on lateralized visual stimuli.

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43.327 Effective Visual Short-Term Storage Capacity and Speed of Encoding are Affected by Arousal

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Effects of spatial cueing on visual attention have been thoroughly investigated during the last 30 odd years. Similar to spatial cueing, temporal cueing seems to afford a performance enhancement to an observer when he or she knows the point in time at which an event will occur (Coull & Nobre, 1998). Varying the statistical distribution of cue-stimulus onset asynchronies (foreperiods) is an effective way of manipulating the observer's temporal expectancies and, presumably, the observer's level of arousal. By use of this manipulation, Vangkilde and Bundesen (2009) found strong evidence that speed of encoding into visual short-term memory (VSTM) increased with the level of arousal in a single-stimulus identification experiment. Here we present a whole-report experiment corroborating the finding that speed of encoding stimulus items (letters) into VSTM increases with the level of arousal. However, by way of contrast, the maximum number of stimulus letters retained in VSTM appeared to decrease as the level of arousal was increased. A possible explanation for this finding is that, as the level of arousal was increased, selectivity deteriorated such that not only the items to be reported but also irrelevant material tended to be encoded into VSTM leaving less storage capacity for the items to be reported. The explanation predicts that performance in otherwise similar partial-report experiments will show that selection of targets rather than distractors becomes less efficient at high levels of arousal. Thus, in terms of the TVA model (Bunde-

sen, 1990), partial report experiments should show that, at high levels of arousal, parameter α (the ratio of the attentional weight of a distractor to the attentional weight of a target) increases.

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43.328 **Selective attention and multisensory integration.**

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Signals from a single physical event can be encoded in multiple sensory modalities, in different brain regions and at different times. Despite great interest, it is unclear how these signals are combined. One persistent controversy concerns the role of selective attention. We have addressed this issue by developing a novel paradigm. Sequential multisensory stimuli were presented (an audio-tactile and an audio-visual) and participants were required to identify one of the two pairs (e.g., was the tactile stimulus paired with a low or a high tone?). Participants were much better at this task when told which sensory modalities they must judge before the stimulus presentation, as opposed to after. This demonstrates that selective attention to specific sensory modalities is fundamental for multisensory binding, as having to divide attention across an additional irrelevant sensory modality evidently disrupts this process.

Acknowledgement: Australian Research Council

43.329 **Decoding the mismatch between expectation and sensory input**

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A regular temporal pattern sets up the expectation that the pattern will continue at the same pace. Because of this expectation, we easily notice random, intermittent changes in a regular pattern, e.g. 'a missing beat'. Here we use high-density EEG to determine whether early visual areas only encode the physical stimulus or also contain representations of the expected sensory input. In a dynamic random dot stereogram, subjects viewed a 5 deg disparity-defined disk that repetitively (1 Hz) moved forward and back 6 arcmin from an annular surround (12° diameter) presented in the fixation plane. Intermittently (30% of time), the pattern changed; either the disparity step was doubled to 12 arcmin or was omitted. The subjects were asked to detect these changes in the pattern. We compared responses from trials where changes, whether doubled or omitted, were correctly identified (hits) with responses from trials in which no change occurred, again correctly identified (correct rejections) within several fMRI-defined ROI's in visual cortex. In V3A and LOC, the early response, consisting of a peak at about 200ms, reflected the magnitude of the disparity modulation. It was absent when the step was omitted, present for the regular step and enhanced when the step was doubled. However, later components of the response to the detected intermittent changes in modulation, i.e. the hits, were very similar. By time-locking the response analysis to the button press we determined that these later components occurred at a fixed timing relationship to the subject's response. Our results suggest that areas V3A and LOC may encode a mismatch between the expected temporal pattern and the actual sensory input, permitting the subject to correctly identify the change and that activity in these areas is causally related to the timing of the decision as reflected by the button press latency.

Eye movements: Methods and gaze

Monday, May 9, 8:15 am - 12:15 pm

Orchid Ballroom, Poster Boards 401 - 416

43.401 **A new technique for the analysis of sequential eye movements**

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Eye movement patterns contain important information about the underlying perceptual and cognitive mechanisms. Traditional area of interest (AOI) measures such as fixation count, fixation duration, scan-path length, and spatial density ignore either the spatial or the temporal aspects of fixation sequences. The transition-probability matrix contains both spatial and sequential information, but it only quantifies pairs of transitions and ignores properties of temporally-extended sequences. Here we describe a new method that captures the statistical regularities in longer sequences

using successor representations (SRs, Dayan, 1993, Neural Computation). Whereas, each cell of a traditional transition matrix represents the frequency of making a single saccade from one AOI to another, the SR uses temporal difference learning to incrementally strengthen the weights of multiple cells based on both recent and predicted future transitions. The result is a matrix representation that integrates over multiple time steps to estimate the expected discounted number of future fixations at location j given a current fixation at location i . This new method was applied to eye movement data from 35 participants that solved items from Raven's Advanced Progressive Matrices test (APM). We performed a principal component analysis on the SRs for each individual participant and used the components to predict the individual APM scores. The two components with highest regression weights had a clear and intuitive interpretation: one captured the systematicity of scanning patterns and the other quantified the tendency to toggle to and from the response area. This supports the theory that high-scoring individuals use a constructive matching strategy and low-scoring individuals use a response elimination strategy. Leave-one-out cross validation demonstrated that these two components explained over 44% of the variance in APM scores, compared to 22% for a traditional transition matrix analysis. The SR technique thus shows great promise for analyzing temporally extended fixation sequences.

43.402 **A new method for comparing scanpaths based on vectors and dimensions**

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We make different sequences of eye movements—or scanpaths—depending on what we are viewing and the current task we are carrying out (e.g. Land, Mennie & Rusted, 1999). In recent years, research efforts have been very informative in identifying commonalities between scanpath pairs, allowing us to quantify, for example, the similarity in eye movement behaviour between experts and novices (Underwood, Humphrey & Foulsham, 2008), or between encoding and recognition of the same image (Foulsham & Underwood, 2008). However, common methods for comparing scanpaths (e.g. 'string-edit', based on Levenshtein, 1966, or 'position measures', see Mannan, Ruddock & Wooding, 1995) fail to capture both the spatial and temporal aspects of scanpaths. Even the newest techniques (e.g. 'Scanmatch', Cristino, Mathôt, Theeuwes & Gilchrist, 2010) are restricted by the fact that they rely on the division of space into Areas of Interest (AOIs), thus limiting the spatial resolution of the similarity metric produced. Here we validate a new algorithm for comparing scanpaths (Jarodzka, Holmqvist & Nyström, 2010) with eye movement data from human observers. Instead of relying on the quantization of space into AOIs, our method represents scanpaths as geometrical vectors, which retain temporal order and spatial position. Scanpaths are then compared across several dimensions—shape, position, length, direction, and duration—and a similarity value is returned for each. Using this new multidimensional approach, our data from two experiments highlights aspects of scanpath similarity which cannot otherwise be quantified: when scanpaths are clearly similar, but are spatially downsampled, for instance. Moreover, we show how scanpath similarity changes depending on task, using our algorithm in comparison to the most popular alternatives. This data demonstrates that our vector-based multidimensional approach to scanpath comparison is favorable to others, and should encourage a shift away from methods which are rooted in the Levenshtein principle or spatial position alone.

43.403 **Participants know best: influence of calibration method on accuracy**

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Calibration of an eye-tracker is associated with several challenges, both theoretical and practical. Theoretical challenges include finding a good mathematical model for the eye as well as a mapping function from eye- to gaze-positions. An important practical aspect is what Goldberg et Wichansky (2003) distinguish as calibration controlled by the experimenter, the system, and the participant. In the first case, the experimenter accepts a calibration target when she has the impression that the participant is fixating the target, additionally verifying that the participant's eye is stable in the video feed of the eye image. In the second, the system decides what raw data

samples should be used for calibration. Participant-controlled calibration is when the participant clicks when looking at the target to calibrate. The current trend is that increasingly more control over the calibration procedure goes to the system; for instance, three of the largest eye-tracker manufacturers all use system controlled calibration as default [EyeLink manual, Tobii manual, and SMI manual]. We recorded 149 participants binocularly on the SMI HiSpeed at 500 Hz, in the three conditions: Automatic, operator, and participant controlled calibration. Accuracy was measured directly after calibration, and again after 15 minutes of participant reading a text. Points for accuracy measurements were identical to calibration points. Accuracy was defined as the minimal distance from a fixation (detected by the algorithm by Engbert and Kliegl (2003)) to the current point that participants were instructed to look at. The difference in accuracy between calibration conditions were tested using Kolmogorov-Smirnov and the Kruskal-Wallis tests. In both cases, participant controlled calibration showed to give significantly more accurate data while system-controlled calibration gives the poorest accuracy. The result will be discussed in relation to data recording practices, participant idiosyncrasies and the types of data analysis that follow recordings.

43.404 Assessing visual delays using pupil oscillations

Jeffrey B. Mulligan¹(jeffrey.b.mulligan@nasa.gov); ¹NASA Ames Research Center Stark (1962) demonstrated vigorous pupil oscillations by illuminating the retina with a beam of light focussed to a small spot near the edge of the pupil. Small constrictions of the pupil then are sufficient to completely block the beam, amplifying the normal relationship between pupil area and retinal illuminance. In addition to this simple and elegant method, Stark also investigated more complex feedback systems using an electronic "clamping box" which provided arbitrary gain and phase delay between a measurement of pupil area and an electronically controlled light source. We have replicated Stark's results using a video-based pupillometer to control the luminance of a display monitor. Pupil oscillations were induced by imposing a high-gain linear relationship between pupil area and display luminance, with a variable delay. A simple model, in which the pupil responds linearly to retinal illuminance with a fixed delay, predicts that the period of oscillation will be linearly related to the applied feedback delay, with a slope of 2, and an x-intercept corresponding to the internal delay. Slopes of the period-vs-delay function for 3 subjects are close to the predicted value of 2 (1.96-2.39), and the implied delays range from 254 to 376 milliseconds. Our setup allows us to extend Stark's work by investigating a broader class of stimuli.

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43.405 Improving gaze accuracy and predicting fixation in real time with video based eye trackers

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Studies of eye movements require accurate gaze, fixation and saccade detection, and most recent studies use video based eye-trackers for this purpose. We present two methods which significantly improve current eye tracking technology, with only minor additions to standard experimental protocols. First, for video-based eye trackers, we characterize a significant pupil-size dependent artifact which systematically biases reported gaze position. By varying display luminance while subjects maintain fixation, we observe corresponding changes in pupil size inducing a gaze position error and obtain an empirical solution to correct it. Applying our technique in software to a commercial video-based eye tracker, we obtain a substantial improvement in the accuracy of gaze position. After correction, the standard deviation of gaze positions around a point of fixation during a 10 second interval reduces by as much as 7.5x and 5.9x in the worst case, with an average reduction of 2.29x and 2.95x across subjects (n=6) and screen positions (m=9), for horizontal and vertical directions, respectively. Additionally, we describe a simple yet effective method for predicting the next fixation during a saccade in flight. Leveraging the relationship between peak velocity and time left in a saccade, we are able to fit model parameters to individual subjects and then use on-line velocity data to predict future fixations. To evaluate the scheme, subjects free-viewed a four minute introduction of a nature documentary. For a stimulus display refresh rate of 100Hz, we correctly predict fixation onsets to within a frame 95% of the time. Our methodology improves gaze accuracy and allows experimenters

a direct access to a window of time immediately around the onset of fixation, opening the door for gaze and saccade contingent experiments using current commercial eye trackers.

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43.406 A Simple Non-Parametric Method for Classifying Eye Fixations

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In the analysis of point-of-gaze recordings made while observers viewed static stimuli, data are usually made more manageable by identifying fixations and representing the remainder as saccades. Methods for classifying fixations have not been standardized, and often employ velocity, acceleration, duration, or stability thresholds. A problem with these approaches is that there are no commonly accepted values for these thresholds, which may be based on a visual inspection of the data, a subjective process, or on biologically plausible values, which are necessarily imprecise, particularly given variation in the spatiotemporal characteristics of eye-movements across observers and different stimulus types. A simple non-parametric method is proposed here for extracting fixations from point-of-gaze data. The method is velocity-based, but, by contrast with existing methods, the velocity threshold for demarcating saccades was derived automatically from the data for each observer and stimulus individually. Peaks in velocity were obtained from the data producing two populations: one less numerous and with higher velocity peaks, interpreted as saccades, and one more numerous and with lower velocity peaks, interpreted as movements during fixations. The velocity threshold to separate the two populations was then obtained using a method based on the gap statistic, introduced by R. Tibshirani and colleagues as a non-parametric method for identifying the optimum number of clusters in a set of data. To remove some apparently extremely short fixations, thought to represent instrumental noise, a duration threshold was also derived automatically from the data. The whole method was tested on data recorded with a video eye tracker running at 250 Hz while observers viewed static natural scenes for over 32000 one-second trials. Its accuracy in classifying fixations was verified by comparison with fixations labelled by independent experts and against existing parametric techniques.

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43.407 A human inspired gaze estimation system

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Estimating another person's gaze is a crucial skill in human social interactions. The social component is most apparent in dyadic gaze situations, in which the looker seems to look into the eyes of the observer, thereby signaling interest or a turn to speak. In a triadic situation, on the other hand, the looker's gaze is averted from the observer and directed towards another, specific target. This is mostly interpreted as a cue for joint attention, creating awareness of a predator or another point of interest. In keeping with the task's social significance, humans are very proficient at gaze estimation. Our accuracy ranges from less than one degree for dyadic settings to approximately 2.5 degrees for triadic ones. Our goal in this work is to draw inspiration from human gaze estimation mechanisms in order to create an artificial system that can approach the former's accuracy levels. Since human performance is severely impaired by both image-based degradations (Ando 2004) and a change of facial configurations (Jenkins & Langton, 2003), the underlying principles are believed to be based both on simple image cues such as contrast/brightness distribution and on more complex geometric processing to reconstruct the actual shape of the head. By incorporating both kinds of cues in our system's design, we are able to surpass the accuracy of existing eye-tracking systems, which rely exclusively on either image-based or geometry-based cues (Yamazoe et al, 2008). A side-benefit of this combined approach is that it allows for gaze estimation despite moderate view-point changes. This is important for settings where subjects, say young children or certain kinds of patients, might not be fully cooperative to allow a careful calibration. Our model and implementation of gaze estimation opens up new experimental questions about human mechanisms while also providing a useful tool for general calibration-free, non-intrusive remote eye-tracking.

43.408 **Inferring locations of objects from gaze in edited motion pictures.**

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Filmmakers often rely upon actors' gaze direction to create a compelling sense of space. We tested whether this "sense of space" leads observers to form correct representations of implied object locations, and whether correct localization is more difficult when a canonical, space-defining gaze event is disrupted. Participants viewed edited films with four shots. In the canonical films, the first shot showed two actors sitting at a table. The second shot showed one actor lifting an object and looking at the other actor. The third showed the second actor appearing to shift his/her gaze to follow the object being placed in one of four locations on the table. The final shot was a close-up showing the object being placed on the table. None of the shots identified the target location except the gaze-shift. In the non-canonical version of the film, the third and fourth shots were swapped. Participants viewed 8-16 of these sequences (half canonical and half non-canonical). Immediately after each sequence, participants were asked which location the object was placed in. At the end of the experiment, participants were asked if they had noticed the different shot orderings. In each of two experiments, participants who were unaware of the different orderings performed more poorly on the non-canonical sequences than participants who were aware of the orderings, while participants who were aware of the different orderings performed better on the non-canonical films. We argue that participants can successfully infer the locations of objects based on gaze, but that they approach these sequences in one of two modes: a default mode in which they are minimally aware of moment-to-moment event structure, and assume typical event sequencing, and a visually focused mode in which viewers attend to fine event structure, allowing them to account for atypical events.

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43.409 **Proactive gaze behavior: which observed action features do influence the way we move our eyes?**

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When subjects observe an object manipulation task, their gaze predicts forthcoming events rather than reactively tracking actor's motion (Flanagan and Johansson 2003, Falck-Ytter et al. 2006). Interestingly, when the same predictable object movement is not the result of human action, the gaze tends to exhibit much less prediction (Flanagan and Johansson 2003). The aim of our study was to understand which are the action features necessary for proactive gaze behavior to appear. We manipulated different parameters of the movement (length, speed and naturalness of the action), to evaluate the effects on observer's gaze proactivity. Subjects sat in front of the experimenter at a 70 cm distance wearing an head mounted gaze tracker. The experimenter, whose motion was recorded by an Optotrak tracking system, performed an object stacking task. The possible distances travelled by the objects were 12, 24 or 48 cm in blocked presentations. The same movements were presented at a natural speed, at a slower pace and at a faster pace. To evaluate the relevance of motion naturalness, the objects was either (i) grasped naturally, (ii) grasped in an unnatural way (with the hand palm upward oriented), (iii) fetched using a pair of pliers, (iii) fetched with the same tool, but in an uncommon way (holding the tool from its tip). Our results indicate that gaze proactivity is quite robust to movement manipulations, suggesting that prediction is also extended to the observation of unusual actions, until they can be performed by a human actor. In a subsequent experiment we replaced the human demonstrator with a humanoid robot. The robot movement was biologically plausible and replicated the human one, so that we could assess the relevance of the actor's appearance on the observer's gaze behavior. The results are discussed in the framework of the mirror neurons direct matching hypothesis (Rizzolatti et al. 2001).

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43.410 **Reading with Normal Vision and with Age-Related Macular Degeneration**

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Purpose: Patients with age-related macular degeneration (AMD) may read with their peripheral retina. Due to crowding effects and poor ocular motor control, these patients may benefit from larger spacing between the letters and from serif type-fonts. In this research we tested the influence of four common type-fonts on reading performance in people with normal vision and in patients with AMD.

Method: Four versions of the MNRead charts were tested on 24 people with normal vision and 19 patients with AMD. The charts were printed using common type-fonts: 1) Times New Roman (proportional spaced, serif), 2) Courier (mono-spaced, serif), 3) Arial (proportional spaced, sans serif), and 4) Andale Mono (mono-spaced, sans serif). Binocular visual acuity was measured with ETDRS.

Results: People with normal vision read best on the Andale Mono chart. On this chart, the largest proportion of people (83%) read the full sentence at the smallest print size (20/13). They also had the best reading acuity ($-.17 \pm .05$ logMAR), critical print size ($.05 \pm .11$ logMAR), and maximum reading speed (233.06 \pm 41.69 wpm). However, on the Times New Roman chart, people with normal vision performed worst in all measures. Patients with AMD read more lines on the Courier chart than on any other charts. On this chart, these patients yielded the best reading acuity ($.56 \pm .17$ logMAR), critical print size ($.70 \pm .20$ logMAR), and second largest maximum reading speed (104.22 \pm 61.43 wpm). Patients read fastest on Andale Mono charts (107.12 \pm 56.57 wpm). In contrast, on the Arial chart, patients with AMD did the worst.

Conclusion: Reading performance of people with normal vision is best on a mono-spaced sans-serif font, while that of patients with AMD is better on a type-font that is mono-spaced and serif.

Acknowledgement: Milton Harris Fund for Adult Macular Degeneration

43.411 **Switching the response direction of pro- and antisaccades: Effects of aging**

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Research using the antisaccade task, in which participants are requested to look away from a visual stimulus, has demonstrated that the ability to control eye movements may be affected by aging. For correct antisaccades it is essential to inhibit a prepotent response towards a stimulus and to select a saccadic response away from it. When pro- and antisaccades are tested within the same block (mixed-task), task switching between pro- and antisaccades and response switching, e.g., a saccade to the left on one trial and a saccade to the right on the next, are required. We investigated the effects of task switching and response switching on performance of younger and older adults, with a focus on response switching. Participants performed single-task blocks, which required only pro- or only antisaccades and mixed-task blocks, in which pro- and antisaccades were assessed. The most important results were that specific task switch costs were observed for error rates of prosaccades in the mixed-task blocks for both groups, suggesting that antisaccade task rules persisted and affected the following prosaccade. The comparison between single- and mixed-task blocks showed that mixing costs were either equal or smaller for older than younger participants, indicating that the older participants were well able to keep task sets in working memory. The most prominent age-difference observed for response switching was that for the older but not younger group task switching and response switching interacted, resulting in less errors when two consecutive antisaccades were made in the same direction. This finding is best explained with facilitation of consecutive antisaccades. Taken together, the present study clearly demonstrated the impact of response switching and a difference between age groups. This finding underlines that it is important to consider this factor in the antisaccade task, especially when investigating task switching and aging.

43.412 Fixation Durations During Scene Transitions

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Fixation durations have been shown to vary with the task definition and the onset of scene transients (Land & Hayhoe 2001; Henderson, 2003). Recent studies have shown that fixation durations may be extended with global changes in the visual stimuli (Henderson & Pierce, 2008; Henderson & Smith, 2009; Pannasch et al., 2010). However these experiments were performed using static images that were interrupted by a noise image that was presented with varying durations. We wanted to study changes in fixation durations under a more natural setting, so we performed eye-tracking experiments while our subjects viewed movies on a computer monitor. Instead of using noise images, we used the numerous scene transitions in the movies to serve as global changes in the visual stimuli. Our analysis focused on fixation durations preceding the scene transition (control set), fixation durations after the scene transition (test set) and on-going fixations at the time of transition onset (cross-over set). We found the fixation durations for the test set to be significantly shorter than the fixation durations for the control set and the cross-over set (1-tailed 1-way ANOVA, $p < 0.01$). Subsequent multiple comparison tests showed that the distribution of fixation durations in the cross-over set was significantly larger than all other conditions. These results support the idea of Process Monitoring in eye movements (Henderson & Smith, 2009). Any global visual change appears to affect not only the length of ongoing cross-over fixations (immediate control), but also shortens the durations of the fixations immediately following that change (delayed control). Additional analyses revealed that this shortening effect lasted for about 220 milliseconds following a scene transition. These results show that fixations are under the influence of moment-to-moment visual and cognitive analysis.

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43.413 Gaze sensitivity on human face

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To evaluate the accuracy of gaze direction in the face-to-face environment, we measured the sensitivity with which the “perceivers” could accurately discern the point on their own face toward which the “viewer” was directing his/her gaze.

In the experiment 1, the viewer was asked to direct his/her gaze to a particular place on the perceiver's face. The perceiver was asked to judge the location of the viewer's gaze. The “error distance” was calculated by measuring the difference between the viewer's gaze point and the perceiver's estimated point, i.e. the distance from the perceiver's actual eye position to the viewer's gaze point on the perceiver's face. In the experiments 2 and 3, the experimental procedure and analysis were identical to those used in experiment 1, except for one instruction given to the perceivers. In the experiment 2, they were required to pay attention to only one of the viewer's eyes when trying to judge the location of the viewer's gaze. In the experiment 3, they were asked to pay attention to both of the viewer's eyes.

The error distance increased as the “distance from eye” of the perceiver increased. In addition, the perceiver's were more sensitive to gaze directed to the right half of their case than to the left one. Further, the perceivers' gaze sensitivity increased when they were instructed to focus their attention on the viewer's both eyes. These results show that perceivers' determine the location of the viewer's gaze by their dominant eye, suggesting that humans have an available capacity for improving gaze sensitivity by concentrating attention on both eyes of the viewer.

Acknowledgement: This work was supported by RARC (Rikkyo Amusement Research Center).

43.414 Oculo-motor patterns induced by reading in peripheral vision.

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There is clear evidence that slower reading in peripheral vision results from shrinkage of the visual span - the number of letters recognized with high accuracy without moving the eyes. Based on this evidence, an ideal-observer model, Mr. Chips (Legge et al., 2002), has been used to simulate saccade planning in reading. This model shows a strong relationship between the size of the visual span and saccade length. One prediction of this model is that reading speed in peripheral vision should be correlated with the saccade length (or more precisely with the horizontal component's length of saccades). This prediction is based on the implicit assumption that regression saccades do not occur too often. We have investigated this issue by measuring eye movements of 34 patients with central field loss (induced by age-related macular degeneration). Patients had to read aloud 14 French sentences displayed in succession (each sentence was displayed on one line). Character size was 3X the individual ETDRS acuity. Each patient had an absolute macular scotoma covering the fovea as assessed by MP1 microperimetry. Ocular data were collected with an Eyelink II eyetracker (500 Hz). The horizontal distribution of fixations was analyzed for each sentence with kernel density estimates. In addition, we assessed whether these distributions contained regions with statistically significant curvature - i.e. regions with a high density of fixations (called clusters hereafter). Results show a high variability of density estimates both within- and between patients: some sentences exhibit very homogeneous distributions while others show clear density peaks. The main finding is that reading speed is significantly slower for sentences that contain fixation clusters compared to sentences without clusters. This relationship between reading speed and the presence of fixation clusters has to our knowledge never been reported and should be taken into account to understand eccentric reading.

43.415 Ocular Motor Fatigue Induced by Prolonged Visual Display Terminal (VDT) Tasks

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The use of Video/Visual Display Terminals (VDTs) for monitoring work has increased in many industries since its first introduction in 1970s. Monitoring work, for example radar operation and factory quality control, is usually monotonous and performed on extended basis for hours, leading to visual fatigue. Depending on the criticality of the job, a few seconds delay as a result of fatigue might be crucial, for example in the case of radar operators. This study examines the possibility of using saccadic eye movements and pupillary dynamics as visual fatigue indicators in extended visual search. Thirty-nine subjects were instructed to perform boring visual search tasks for an hour using a computer screen. Eye movement and pupil size data are broken down into 12 time-blocks of 5 minutes each for analysis against time. Linear regression shows a significant gradual decrement trend in average saccadic velocity during the experiment ($R^2 = 0.58$, $F(1,10) = 13.73$, $p < 0.01$). The study also demonstrates a very strong relationship between reduction in pupil size fluctuation and time into the experiment ($R^2 = 0.82$, $F(1,10) = 44$, $p < 0.01$). While visual search performance is not affected, the regression results is consistent with the result from the subjective visual fatigue and sleepiness survey which indicates that subjects are significantly more visually tired at the end of the experiment. Our study therefore suggests the possibility of using average saccadic velocity and pupil size fluctuation across time as the indicators of fatigue. Future validation studies should extend the duration and increase the demand of the visual search task, allowing ocular behaviours to be captured at the point where fatigue has affected visual search performance.

43.416 **The stimulus to accommodation: changes in retinal contrast matter, not the spatial frequency content.**

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Accommodation operates to optimise retinal-image contrast. There is a long-standing debate, however, about the role of different spatial frequencies. The fine-tuning hypothesis posits that high frequencies play an increasing role as the system approaches sharp focus. Yet empirical data show that adding mid-range frequencies (above 6-8 cpd) has little effect on accommodation performance. Recently, we presented an analysis of changes in retinal contrast with accommodation, based on real-eye optics, that reconciles these apparently contradictory ideas (MacKenzie, Hoffman & Watt, 2010, JOV). We suggested that responses are driven by overall retinal-contrast changes with changes in accommodation, implying that the 'contribution' of particular frequencies depends on the relative strength of the signal they provide in a given stimulus. Here we test this model empirically. The contribution of different frequencies has typically been determined by measuring changes in variability of steady-state accommodation responses, or accommodation gain in response to modulations in focal distance. Interpreting such data is complicated because the optimal accommodative distance is unaffected by stimulus content. Instead, we used a multiple-focal-plane display to present different combinations of spatial frequencies at different focal distances. We used our model to make quantitative predictions about the biases in accommodation that would result. Accommodation responses were well predicted by the model. High spatial frequencies (~16 cpd) had a clear effect on accommodation when the signal at mid-range frequencies was weak (low contrast, narrow band). Consistent with previous experiments, however, higher frequencies had little effect when the mid-range signal was strong (high contrast, broadband). The results are consistent with the idea that accommodation is driven by overall changes in retinal contrast, summed across different frequency components. This suggests that the 'role' of different spatial frequencies in accommodation control is not fixed, but is an emergent property of the signal they provide in particular stimulus contexts.

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Binocular vision: Eye movements

Monday, May 9, 8:15 am - 12:15 pm

Orchid Ballroom, Poster Boards 417 - 425

43.417 **Extra-retinal signals affect the perceived speed of 3D motion**

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When tracking an object moving in depth, eye vergence changes to minimise the object's absolute disparity. It is widely held that extra-retinal cues about changes in the orientation of the eye do not support perceptual estimates of motion-in-depth. However, we have shown (Welchman et al, 2009, *Vis Res*, 49, 782) that extra-retinal signals support judgments of the sign of motion-in-depth (approaching vs. receding). Here we ask whether extra-retinal signals affect judgments of 3D speed. Observers (n=6) fixated a small target surrounded by a large background. We induced (perceptually unnoticeable) vergence pursuit movements by continuously varying the lateral position of the left and right eyes' images in counter-phase following a sinusoid (frequency 1/4 Hz; amplitude 34 arcmin). On each trial, the target's disparity relative to the background changed at one of five rates, so that the target was seen as approaching at different speeds. Observers judged whether the speed of the target was faster or slower than the mean of the stimulus set. We determined psychometric functions in four conditions: when the eyes were moving to (a) converge or (b) diverge, and when the eyes were nearly static in (c) near or (d) far vergence positions. We found a shift between the psychometric functions of 30% in the rate of change in relative disparity when the eyes were moving, such that an approaching target was seen as faster during convergence and slower during divergence. In contrast, we observed no shifts in the psychometric functions when the eyes were nearly static. This demonstrates that extra-retinal signals support judgments of 3D motion magnitude as well as of

sign. Specifically, we show that 3D speed judgments are affected by extra-retinal signals about changes in eye orientation, but are unaffected by extra-retinal signals relating to the static orientation of the eyes.

Acknowledgement: BBSRC, UK

43.418 **Assessing vergence-accommodation conflict as a source of discomfort in stereo displays**

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Stereo 3D (S3D) is becoming increasingly commonplace in cinema, television, gaming, and elsewhere. S3D viewing is known to cause visual discomfort and fatigue. Conflicts between vergence and accommodation are one source of such symptoms. We measured the combinations of vergence and accommodative stimuli that yield comfortable S3D viewing. We also examined whether the two standard optometric measures used in prescribing optical corrections predict the comfortable combinations for S3D. In the first two experiments, we used a volumetric display to manipulate vergence and accommodative stimuli independently. Experiment 1 examined the effect of viewing distance. For three base distances (0.4, 0.77, and 10m), we assessed discomfort induced in cues-consistent and -inconsistent conditions. In consistent conditions, the vergence and accommodative stimuli were always equal and they changed in unison from one stimulus presentation to another. In inconsistent conditions, the accommodative stimulus was fixed while the vergence stimulus changed as in the consistent conditions; the latter condition thereby created the vergence-accommodation conflict associated with S3D viewing. The conflict was always crossed (vergence stimulus nearer than accommodative stimulus). Experiment 2 investigated how the sign of the conflict affects discomfort. Using the same base distances, we fixed the accommodative stimuli and changed vergence stimuli in the crossed and uncrossed directions: respectively closer and farther than the accommodative stimulus. The results showed that the comfort zone narrows with increasing distance and that crossed disparities are better tolerated at long distances and uncrossed at near distances. In Experiment 3, we used a phoropter to measure each subject's phoria and relative vergence range. The phoria and range measurements were significantly correlated with discomfort reported in Experiments 1 and 2, which means that these standard clinical measurements can predict the conditions in which subjects will experience discomfort and fatigue when viewing S3D.

43.419 **Eye movements during vergence effort in stereoscopic ocular pursuit task and their relations to visual fatigue and stereopsis**

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Stereoscopic viewing of simulated scenes for long durations is getting increasingly popular and it is important to understand the sources of discomfort. It is generally acknowledged that one major problem results from the mismatch between vergence and accommodation cues. This sensory conflict is supposed to entail visual fatigue, while some studies have shown that fatigue could occur even if the depicted stereogram remains in the focus range of the accommodative system, especially in the presence of motion in depth. It is thus unclear why visual fatigue may emerge in absence of strong accommodative demand. To address this question, we evaluated whether visual fatigue might be related, in stereoscopic displays, to the vergence system disturbance. Using a stereoscopic ocular pursuit task to fatigue the visuomotor system, we dynamically measured the accuracy of eye movements. Observers saw a moving-in-depth fixation cross whose displacement was either back to front or front to back relative to the screen plane. This fixation cross was surrounded by a frame composed of small black and white squares to help maintain stereoscopic fusion. Three sessions of stereoscopic ocular pursuit and their control condition were designed according to different convergence demands (+/- 90, 60, 30 and 0 arc minutes of departing/arriving disparity). After each trial, performances in judging the angle of a vertical dihedron in an open-book configuration were assessed using random-dot stereograms. Results revealed that the perception of 3D shape was progressively affected by the strain of the visuomotor task, even when the disparities during the pursuit remained within the focus range. These results overall argue for a potent involvement of in-depth-motion in producing visual symptoms for stereoscopic content. Findings are discussed in light of a sensory-motor hypothesis - which

claims that causes of visual fatigue are adaptively motor-dependent –, and of their implications in investigating health-related-questions on traditional stereoscopic displays.

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43.420 Eye movements and reaction times for detecting monocular regions in binocularly viewed scenes

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Our binocular view of the world is scattered with monocular regions, that only one eye can view. These occur at each depth edge. In previous research, we found that monocular target items are detected faster than binocular targets in a stimulus filled with binocular distractors. Here we explore whether monocular targets also direct eye movements whilst observers perform a visual search task.

Participants performed a classic search task to detect a target C amidst 254 distractor O's, in one of 3 conditions: 1) monocular target, all distractors binocular, 2) one monocular distractor, all other distractors & target binocular, 3) target and distractors binocular. Stimuli were presented using a modified Wheatstone Stereoscope. Reaction times for target detection were measured and eye movements were recorded using an infrared eye tracker. Stimulus onset was contingent upon central fixation. The target was always located towards the left or right side of the stimulus. We measured whether the first saccade was towards the half of the stimulus that contained the target.

On average, reaction time followed the pattern previously observed: if the target was monocular, reaction times were shortest, while if there was one monocular distractor, and the target was binocular, reaction times were longest. In condition 2 we found that the slower reaction times were mirrored by lower rates of correct eye movements. In condition 1 we observed that individuals giving faster reaction times showed a higher number of correct saccades, while those with slower reaction times tended to show fewer correct saccades.

Our results suggest that moving the eyes rapidly towards a monocular region may aid its fast detection. This could help in the identification of object edges, and in the perception of depth from binocular disparity.

43.421 Vergence, pin interval, and the double-nail illusion

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The double-nail illusion arises when the two eyes converge on halfway between the pins. Mallot and Bideau (1990) found that the illusion often arose even when the eyes converged on either pin and concluded that stereo matches in the fixation plane were preferred. This study investigated the appearance of double-nail display with varying pin interval. The stereograms that consisted of vertical bars were displayed on a mirror stereoscope in a darkroom. Each presentation was preceded by a stereoscopic fixation stimulus that was held 40 cm from the observer. Immediately after this fixation was turned off, the double-nail display was flashed for 200 msec. One pin replaced the preceding stimulus and the other appeared beyond or in front of the fixated pin. The task was formulated as a two alternative forced choice between "two lines visible" (frontoparallel percept) and "three lines visible" (medial percept). Three subjects performed 30 trials for each of the pin interval in a randomized sequence. The display with small pin interval was perceived as two lines. With larger interval, the frequency of three-lines percept increased. We then conducted another experiment to measure Panum's fusional area on the fiducial line. Immediately after a fixation was turned off, a pin was flashed for 200 msec. The pin appeared beyond or in front of the fixated target. The task was formulated as a two alternative forced choice between "two lines visible" and "one line visible". Analyzing data, we found that the double-nail display was perceived as two lines when they were within the Panum's fusional area. This result indicates that a stimulus that the eyes converge does not always generate fused image.

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43.422 Single-trial decoding of binocular rivalry switches from oculometric and pupil data

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Pupil and gaze measurements have been shown to contain a surprising amount of information related to visual and cognitive processes. For instance, changes in pupil size have been associated with perceptual switches (Einhäuser et al., 2008), target detection (Privitera et al., 2010) or cognitive load (Kahneman & Beatty, 1966) and it has been suggested that microsaccades could reflect the orienting of attention (Laubrock et al., 2010). Here we consider a multivariate pattern analysis to study the diagnosticity of various pupil and gaze measurements available from binocular eye-tracking recordings to predict the perceptual state of human participants and the occurrence of switches over time during a binocular rivalry task. Our paradigm involves the presentation of a brighter stimulus in one eye and a non-fusible less bright stimulus in the other eye, inducing an alternation between two percepts.

In agreement with previous results (Fahle et al., ECVF 2010), we find that a perceptual switch to the darker stimulus results in significant pupil dilatation, starting significantly before manual report. On the other hand, a perceptual switch to the brighter stimulus results in an opposite, but similar amplitude, pupil constriction thus dismissing a motor artifact explanation (Hupé et al., 2008) and clearly vouching for an association between rivalry switches and pupil size changes. We further demonstrate that it is possible to reliably decode perceptual switches on a single-trial basis. Using a feature selection method, we investigate the predictive power of various oculometric and pupil measurements. Overall our results confirm the link between changes in pupil size and changes in perceptual states and bear important consequences for future studies of binocular rivalry.

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43.423 A Comparison of Self-Reported and Measured Autostereogram Skills with Clinical Indicators of Vergence Ability in Esophores

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Perception of the disparity-defined form in autostereograms requires achieving and maintaining the precise vergence angle necessary to place the intended left and right images on corresponding areas of the two retinas. Most commercially available autostereograms are designed to be viewed only with one vergence posture, usually the parallel or "wall-eyed" technique¹, meaning that the visual axes need to converge by one or more periods of the pattern to a point farther from the viewer than the plane of the stereogram. Converging the eyes ("cross-eyed" technique) in front of these autostereograms by one or more periods of the pattern will reverse the depth direction of the stereoscopic image, perhaps making the form more difficult to perceive. Our previous work² compared common clinical indicators of vergence ability with subjects' self-reported and measured autostereogram skills and found significant differences between those with poor versus good self-reported and measured autostereogram skill for vergence facility, near phoria, and TNO stereoacuity for subjects who were exophoric at near. The present study was undertaken to compare clinical indicators of vergence ability to perceived and measured autostereogram skills in esophores. Our results show that esophores whose self-rated and measured autostereogram skills were "poor" demonstrated significantly poorer performance on clinical tests of vergence facility and were more likely to demonstrate differences in threshold performance for crossed vs. uncrossed disparities on the TNO stereoacuity test than were subjects with "excellent" autostereogram skills. Attempts to fuse using "wall-eyed" vs. "cross-eyed" viewing did not differ between the two groups for those subjects able to perceive the autostereogram form.

Acknowledgement: None

43.424 Is the midline dependence of Binocular Depth Contrast based on the retinal midline or the head-and-body midline?

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We recently reported that induction of perceived inclination (visual pitch), the well-known Binocular Depth Contrast phenomenon (BDC) of Werner (1938) & Ogle (1950) does not cross the median plane but is restricted to the side of the visual field containing a unilateral inducer (Hudson, Li, & Matin, PNAS, 2008). The present experiments investigated whether the median-plane restriction relates to the midline of the retina or the midline of the head-and-body. **METHOD:** The experiments involved 12 conditions in which each employed a unilateral inducer and a unilateral test target along with a small foveal fixation target in otherwise total darkness. The inducer and test target were either on the same or opposite sides of the retinal midline while simultaneously being on either the same or opposite sides of the head-and-body midline. All combinations were examined (same retina/same head-and-body; same retina/opposite head-and-body; opposite retina/same head-and-body; opposite retina/opposite head-and-body). The inducer (70o-long) and test target (33o-long) were single pitched-from-vertical straight lines separated by either 16.7o or 33.3o and either 8.3o, 25o, or 41.6o from each midline (all combinations of retinal and head-and-body eccentricities). Inducer pitch ranged over +25o (topforward/topbackward). Visually perceived erect (VPE) settings of the test line to appear erect in the frontoparallel plane were measured psychophysically. **RESULTS:** Although both midlines contribute to BDC, the retinal midline plays a major role and the head-and-body midline plays a minor role: Thus, the slope of the VPE-vs-pitch function was .38 for the same retina/same head-and-body condition and .28 for the same retina/opposite head-and-body condition, but was only .07 for the opposite retina/opposite head-and-body condition and .17 for the opposite retina/same head-and-body condition. A weighted average of the two midlines inserted into the 2-channel/3-stage neuromathematical model that accounts for the earlier results also accounts for the present results.

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43.425 Stereoacuity of Athletes in Primary and Non-Primary Gazes

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INTRODUCTION: The ability to perceive depth information is critical to athletes during competition - to localize, track and react to objects, teammates, and opponents. Traditionally, stereopsis is measured at near distance and measured along the normal line of sight (primary gaze). The purpose of this study was to compare primary to non-primary stereoacuity at far in athletes.

METHODS: Stereoacuity was measured to a higher threshold than traditionally assessed, and was part of a comprehensive visual performance evaluation. One hundred thirteen athletes, age 12 to 38 years, were evaluated at sports performance training centers and optometric practices. Four Wirt-type circles were presented, with one circle having stereoscopic float induced by lateral disparity, ranging from 240 to 12 arcsec. Circles were displayed on a high frequency computer monitor synchronized with active shutter eyewear at 4.9 m. Utilizing a staircase algorithm, subjects responded in a 4-choice forced-choice paradigm to determine threshold. Stereoacuity was measured in primary gaze and two non-primary gazes (head turned with gaze over the right shoulder and then over the left shoulder).

RESULTS: Average (sd) stereoacuity thresholds were 27.5 (62.4) arcsec in primary gaze, 46.8 (28.9) arcsec in left gaze and 42.2 (42.5) arcsec in right gaze. Repeated measures analysis of variance showed that primary gaze stereoacuity was significantly better than non-primary gaze over the left shoulder ($p=0.0059$) and right shoulder ($p=0.0499$). Sixty-one percent (69 of 113) of the subjects demonstrated reduced stereoacuity in at least one non-primary gaze angle.

DISCUSSION: Considering the widely varying visual gaze demands athletes face in most sports, when assessing an athlete's stereoacuity, primary and non-primary gaze angles should be measured. Considering the average stereoacuity was 27.5 arcsec, with best being 12 arcsec, test methods should be more sensitive to determine stereoacuity threshold for athletes.

Face perception: Features and configuration

Monday, May 9, 8:15 am - 12:15 pm

Orchid Ballroom, Poster Boards 426 - 439

43.426 The contribution of texture and shape to face aftereffects for identity versus age.

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Background: Faces have both shape and texture, but the relative importance of the two in face representations is unclear. **Objective:** We determined the relative contribution of shape and texture to aftereffects for facial age and identity. We then assessed whether adaptation transferred from texture to shape and vice versa, to determine if these were integrated in a single representation. **Methods:** The first experiment examined age aftereffects. We obtained young and old images of two celebrities and created hybrid images, one combining the structure of the old face with the texture of the young face, the other combining the young structure with the old texture. This allowed us to create adaptation contrasts where structure was the same but texture differed between two adaptors, and vice versa. In the second experiment, we performed a similar study but this time examining identity aftereffects between two people of a similar age. In the last experiment, we used the normal and hybrid images to determine if adaptation to one property (i.e. texture) could create aftereffects in the perception of age in the other property (i.e. shape). **Results:** Both texture and shape generated significant age aftereffects, but texture contributed the majority of adaptation (77%). Both texture and shape also generated significant identity aftereffects, but the balance was different here, with texture accounting for only 32% of adaptation. In the last experiment, we found no transfer of age aftereffects between texture and shape. **Conclusions:** Shape and texture contribute differently to different face representations, with texture dominating for age and shape dominating for identity. The lack of adaptation transfer may indicate that these properties are encoded independently.

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43.427 Strength of the adapter signal, not adapter discriminability, produces reduced facial expression after-effect in crowding

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Crowding, in which a target stimulus is presented with similar flankers, not only impairs the discriminability of the target but also reduces its power to generate adaptation effects. However, little is known about the causes of this reduced adaptation with crowding, especially for the facial expression after-effect. We generated a set of original caricature faces each made of 6 facial features (2 eyebrows, 2 eyes, nose and mouth). The shape of the mouth was varied from concave to convex gradually, signaling the facial expression from sad to happy. We then moved the facial features of the original caricature face (f) closer to the mouth; feature crowded (ffc), or minimized the face contour, contour crowded (fcc), to make the discrimination of mouth harder. In experiment 1, using the above-mentioned stimuli, we tested the crowding effect by asking subjects to judge whether the face stimulus was a sad or happy face. In experiment 2, we used f, ffc or fcc face stimuli with happy expression as an adapter and f as a test. The subjects' task was to judge whether the test face was sad or happy. Only contour crowding in contrast to feature crowding significantly impaired the facial expression discrimination. Yet both feature-crowded or contour-crowded caricature faces produced a facial expression after-effect when utilized as adaptors. Compared to a control condition with a non-crowded adapter, contour crowding and surprisingly feature crowding reduced the after-effect significantly ($p < 0.001$, $p = 0.04$ respectively). Given that only contour crowding impaired the discriminability of the adapter, the reduced adaptation for the feature crowding condition argues against poor adapter discriminability as the source of the weakened aftereffect. Instead, our results suggest that the strength of the facial expression after-effect depends on the strength of the adapter signal.

Acknowledgement: HSS - RG1 given to HX

43.428 Inter-feature Transfer Of Aftereffects: Evidence Of Adaptation In Whole Face Representations

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Background: It is hypothesized that upright faces are represented holistically in the human visual system, with only local part-based feature representations for inverted faces. Objective: To test this, we used a novel inter-feature adaptation transfer technique to determine if face aftereffects resulted from adaptation in whole-face representations. Method: We divided face images into upper and lower halves, and examined first if each half created aftereffects for its own perception (within-feature adaptation), and second if each half created aftereffects for perception of the other half (inter-feature transfer). This was done for upright face identity, inverted face identity, and expression judgments for upright happy versus sad faces. Results: Inter-feature transfer of adaptation was significant for upright face identity, and equivalent in magnitude to within-feature adaptation. No significant inter-feature transfer was found for inverted identity aftereffects. For upright facial expression, we found robust within-feature adaptation but no inter-feature transfer. Conclusions: Most, if not all, identity aftereffects of upright faces may be generated in integrated whole-face representations, but not for inverted identities, consistent with hypotheses of an orientation-dependent expert holistic mechanism. However, our findings for expression suggest that happy/sad features in upright faces may be processed at a featural level.

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43.429 Body-selective neural mechanisms prefer a whole body over the sum of its parts

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Recent evidence reveals specialized processing mechanisms for human bodies, including the discovery of body-selective areas in occipito-temporal cortex and a face-size body inversion effect. These findings have led to the suggestion that like faces, bodies are processed by holistic mechanisms. Evidence for holistic body representation includes a behavioral Whole-Part effect, and a step-like increase in response of the fusiform body area to large relative to small body parts. However, no study has directly examined whether body-selective mechanisms indeed prefer a whole body over the sum of its parts. Here we used fMRI to determine whether body-selective areas in occipito-temporal cortex discriminate intact vs. scrambled body configurations. Subjects were presented with blocks of faceless bodies that were intact, headless, armless or legless, in either whole or scrambled (part-based) configuration. For each subject we defined face, body and object-selective areas with a separate functional localizer scan. Body-selective areas showed a higher response to whole than scrambled bodies for all body types. The fusiform face area (FFA) showed higher response to whole than scrambled bodies only for intact bodies. This effect was not significant for headless, armless or legless bodies. The occipital face area (OFA) and the object-general areas showed no preference for whole over scrambled bodies. Finally, both FFA and OFA showed lower responses for headless bodies relative to intact, armless and legless bodies, which included a head. These findings suggest that holistic representation of human bodies uniquely exists in body-selective areas, but not in object-general areas. The response of face-selective areas was influenced by the presence of the head and may reflect mechanisms of face imagery, which are more likely to be generated by whole intact bodies than by headless or scrambled bodies.

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43.430 Contribution of SF and Orientation to upright and inverted face perception

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So far, the contribution of spatial frequency (SF) and orientation to face perception has been explored separately although these dimensions are jointly encoded during primary visual processing. Namely, it has been shown that

SF around 12 cycles per face (cpf) and horizontal face structure optimally convey face identity, respectively. In the present experiments, we delineated the primary visual information most useful for face perception by manipulating the content of face images both in orientation and SF. Picture-plane inversion was used to evaluate the face specificity of the observed SF-orientation effects. We asked participants to match upright and inverted faces that were filtered in the Fourier domain. Faces in a pair contained horizontal, vertical or the combination of horizontal and vertical ranges of information in low (between 2 and 8 cpf), middle (between 8 and 32 cpf) or high SF (between 32 and 128 cpf). The advantage for processing horizontal compared to vertical bands of face information arose in SF located between 8 and 16 cpf. It decreased at lower (2-8 cpf) and higher SF (32-128 cpf) ranges. Picture-plane inversion decreased the horizontal advantage mostly between 8 and 16 cpf. Our findings suggest that the expert processing of upright faces is selectively tuned to horizontally-oriented face structure carried by intermediate SF bands. This SF-orientation tuning is lost with inversion indicating that it results from observer-dependent face-specific mechanisms.

43.431 Internal feature position in faces is coded relative to external contour: adaptation aftereffects, neural coding models, and 3D head rotation.

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We explore the relative importance of coding internal feature (e.g., eye) position relative to other internal features versus external head contour, and the possible role of head contour in coding feature position view-invariantly. All experiments employ the logic that size of a face aftereffect for a fixed physical deviation of adaptor gives a measure of sensitivity of coding along that axis in face-space, reflecting the slope of underlying two-pool neural response functions (see Susilo, McKone & Edwards, 2010, Vision Research). In Experiment Series 1, the baseline aftereffect was for +50 pixels vertical manipulation of eyeheight in a full head with all internal features and head contour present. Results were: (a) the aftereffect from a +50 pixels eyeheight adaptor in an internal-features-only stimulus was as large as baseline, arguing eye position is coded very accurately relative to only internal features; (b) the aftereffect was as large in an external-features-only stimulus (i.e., face and hair outline retained but nose and mouth ablated), arguing eye position is coded equally accurately relative to only external features; (c) the aftereffect from a more extreme eyeheight adaptor in an internal-features-only stimulus was larger, arguing linear 2-pool coding continues, in the absence of external contour, for eye positions that would normally be outside the head; and (d) the aftereffect from the extreme adaptor went to zero when head contour was added back in, arguing external contour trumps internal features and neural responses drop immediately to zero when the eyes are outside the face. In Series 2, we find mouth position aftereffects are as large from several manipulations breaking the first-order configuration of a front-view face (e.g., mouth left, mouth down-and-right) as from manipulations that do not (e.g., mouth up). This argues the purpose of the coding relative to head outline is to allow for 3D head rotation.

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43.432 High order invariance in spatial frequencies implied by distinct latency differences of face induced N200 components

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It is well recognized that spatial frequency plays an importance role in face perception revealed as 10 cycle/face optimal frequency (Keil, 2008) and hybrid faces (Schyns and Oliva, 1999). However, the neural mechanism of face spatial frequency processing remains largely unknown. In this study, we recorded intracranial evoked potentials from epilepsy patients with implanted subdural electrodes when 40 face pictures of different identities, genders and emotional expressions were presented in low spatial frequency (LSF) or high spatial frequency (HSF) forms while the subjects were simply required to detect rare oblique pictures as catch trials. We found N200 component on 17 electrodes from 6 subjects. HSF faces induced a longer N200 latency compared to LSF faces and a significant interaction has been found between spatial frequency and gender of the face. Female faces in HSF form generate longest latency and LSF female faces induced the shortest one, leaving the LSF and HSF male faces in between. However,

only the differences between LSF and HSF female faces are significant in an ad-hoc analysis. A possible explanation is that female faces are smoother and extending to broader frequency ranges. So the difference between mean frequencies in LSF and HSF forms would be larger for female faces than for male faces. But spectrum analysis of the stimuli rejected this and other simple features statistics possibilities. However, we do find that HSF male faces have more SIFT keypoints (Lowe, 1999) than HSF female faces. Since it is also conflict with the fact that the number of SIFT descriptors of LSF male faces is much lesser than HSF male faces but their N200 latencies are not significantly different, we believe that a high order face invariance somehow related with spatial frequency is necessary to understand the face perception and its neural dynamics.

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43.433 The diagnostic features used for recognizing faces under natural conditions

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Classical studies of face perception have used stimulus sets with standardized pose, feature locations and extremely impoverished information content. It is unclear how the results of these studies translate to natural perception, where faces are typically encountered in a wide variety of viewpoints and conditions. To address this issue, we used a 2-AFC coherence paradigm, a novel method of image generation and photographs of real faces presented at multiple viewpoints in natural context. A library of portraits, with 10-15 images of each person in various positions, was collected and in each image the prominent features (eye, mouth, ear, etc.) were labeled. Images were decomposed using a bank of Gaussian-derivative filters that gave the local orientation, contrast and spatial frequency, then reconstructed using a subset of these elements. Noise was added by altering the proportion of filter elements in their correct, signal location or a random noise location. On each trial, subjects first viewed a noiseless image, followed by noisy versions of a different exemplar of the same face and of a different face, and had to identify which image matched the person in the source image. The proportion of elements in the correct location on each trial was varied using a staircase procedure to maintain 78% correct responses. Each labeled feature was then analyzed independently by reverse correlation based on correct and incorrect trials. For correct identification, a significantly higher proportion of signal elements were necessary in the hair, forehead and nose regions, whereas elements in regions indicated as diagnostic in classical studies based on standardized stimulus sets, such as eye and mouth, were significantly less influential. These results are in odds with earlier findings and suggest that under natural conditions humans use a more extended and different set of features for correct face identification.

Acknowledgement: NIH

43.434 Exploring chimpanzee face space

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Face space is a powerful framework that can explain various face processing phenomena in humans, including poor recognition memory for unfamiliar faces and other-race effects, however, it has yet to be applied to other species. We examined whether the face space framework can aid our understanding of face processing in the chimpanzee, a species that shares many of the same cognitive specializations for face processing as humans. Five chimpanzees discriminated all combinations of 20 female faces (380 dyads repeated 10 times), including a 20-face population average, in a matching-to-sample task. Multidimensional scaling was then used to generate a two-dimensional plot representing discrimination performance (% correct). Typicality ratings for the 20 faces were also obtained from human primate experts. From the MDS plot, we measured the length of each identity vector with regard to the origin, the vector angle between each face in the 190 dyads, and calculated the mean typicality ratings. As predicted by the face space model, the average face was positioned centrally in the MDS plot, having the second shortest vector. Human experts' typicality ratings were significantly correlated with vector lengths, where the average face was rated most typical. Chimpanzees' performance was signifi-

cantly correlated with both the typicality ratings and vector lengths, such that distinctive faces were discriminated better than typical faces. Notably, the worst performance was for the average face. Finally, performance also correlated with vector angle. Faces separated by the shorter angles, suggesting similar diagnostic features, were discriminated more poorly than faces separated by large angles. An analysis of the faces suggested that the dimensions could be described as lower face width and overall head size. These data suggest that face processing in chimpanzees fits within a face space framework, and supports evolutionary continuity in face processing in Hominoids.

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43.435 Sibling Rivalry: Facial distinctiveness and binocular rivalry

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When high and low luminance contrast images are presented separately to each eye in conditions of binocular rivalry, the percept of the stronger (high luminance contrast) image tends to dominate. We tested for parallels to this contrast dependence in faces where the "contrast" of the stimulus corresponded to the face's "identity strength." Faces are thought to be represented in a multidimensional face-space that is likely to be neuronally instantiated in the ventral temporal cortex. According to this hypothesis an individual face is represented by how it deviates from an average face (the origin of the face-space), and face-contrast varies as the magnitude of the deviation of a given face from the prototype. We asked whether more distinctive faces would be more likely to dominate in rivalry. Methods: Distinctiveness was varied by distorting an original face by locally expanding or contracting the facial features relative to a midpoint on the nose. These distortions had the advantage of preserving many of the low-level image features while varying how atypical the faces appeared. Observers viewed the display through a stereoscope and were presented with the original face to one eye and a distorted (sibling) face to the other eye to create a condition of binocular rivalry. During continuous viewing they reported whether they perceived the average face, the distorted face or neither. Results: Observers perceived the distinctive faces for longer periods of time than the average faces. Conclusion: The results suggest that more distinctive faces may tend to have a higher effective contrast in rivalry, suggesting in turn that the rivalry may partly depend on the encoding of the configural characteristics defining the faces.

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43.436 The composite face illusion and its disappearance with misaligned faces: an effect of metric distance or part separation?

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Strong evidence that faces are perceived holistically/configurally comes from the composite face effect/illusion: identical top halves of a face are perceived as being slightly different if they are aligned with different bottom halves. The illusion disappears when the bottom half of the face is moved away from the top half, so that the top and bottom halves are spatially misaligned. One unresolved issue is whether the composite illusion disappears in the misaligned condition because the two halves do not form a whole object anymore (i.e., they form two segmented parts), or because the bottom part is located away from the top part. To address this issue, 12 participants had to match two top halves of composite faces presented sequentially. The experiment was characterized by 3 conditions ("same": both halves identical; "different": both halves different; "composite": top half identical, bottom part different) and 7 levels of alignment between the top and bottom halves: from spatially aligned, forming a whole coherent face, to completely misaligned (100% width of the face). Twenty-three base face identities were used. In the composite trials, accuracy rates decreased significantly compared to "same" trials, only in the completely aligned condition. Correct response times were also significantly increased only in that condition. Strikingly, even a small spatial misalignment (16.7% width of the face) between top/bottom parts in the composite face paradigm disrupted completely the influence of the bottom part on the perception of the top part, so there was no difference between all other levels of (mis)alignment. This observation implies, practically, that it is not necessary to use a wide spatial misalignment in such studies. From a theoretical standpoint, these data show that it is the spatial alignment/separation of the facial halves rather than the metric distance between the face parts that explain the presence/absence of the composite face effect.

43.437 Face inversion with sequential restricted viewing

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Face and object recognition is predicated on the integration of features into wholes. Face recognition is often considered different from recognition of other classes of objects, because integration of face features is "holistic" or simultaneous, whereas integration of other object features is "piecemeal" or sequential. This dissociation suggests differences in spatial and temporal integration between holistic and piecemeal processing, however, face recognition is rarely tested under conditions that demand significant temporal integration. Here, we used a restricted viewing paradigm to force subjects to process face features sequentially. Restricted viewing involved a moving aperture that allowed viewing of only a single feature at a time. In Experiment 1, faces were presented using restricted viewing at five different viewpoints (in-depth rotations) and two different orientations (upright and inverted), and subjects made a two-alternative forced-choice (2AFC) male/female judgment. In Experiment 2, faces were presented at one viewpoint using two different restricted viewing methods and three different whole-viewing methods, and subjects performed a 4AFC identity judgment. In both experiments, accuracy measures showed significant effects of orientation (i.e., "inversion" effects) for both whole viewing and restricted viewing. Viewing-time maps created from subjects' exploration paths during restricted viewing showed that subjects sequentially sampled multiple features, with most of the time spent in areas around the eyes and mouth. The eye/mouth exploration pattern was found even at extreme viewpoints (e.g., 90 degrees) when the nose in profile was very salient and one eye was occluded. There was no difference in the pattern of viewing times across orientations. The results show that the face "inversion effect" exists over a relatively broad time window. The results suggest that "holistic" processing may involve feature integration at multiple time scales.

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43.438 The use of horizontal information underlies face identification accuracy

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Faces are recognized more easily when upright than inverted. Contrary to many theories, recent studies suggest that the inversion effect is not due to subjects using different spatial or spatial frequency information. So the question remains: What causes the inversion effect? Here we examine whether sensitivity to information at different orientations may account for the face inversion effect. Face identity is conveyed primarily by information in the horizontal band (Dakin & Watt, *J Vis* 2009), and observers are more sensitive to this information for identification of upright faces than inverted faces (Goffaux & Dakin, *Front Psychology* 2010; Pachai et al., *VSS* 2010). To determine whether these sensitivity differences are directly associated with face identification, we assessed orientation tuning of upright and inverted face identification using noise masking. Stimuli were masked with Gaussian noise filtered to contain information in one of 8 orientation bands (bandwidth = 23deg) ranging from -90 (vertical), through 0 (horizontal) to 67.5 degrees. We measured 10-AFC identification thresholds in 16 subjects in each orientation condition, as well as a white noise baseline condition, with upright and inverted faces. On average, we found strong masking centred on the horizontal band for upright faces and significantly weaker masking for inverted faces. Furthermore, the degree of horizontal tuning was strongly correlated with baseline identification performance for upright, but not inverted, stimuli. Finally, the change in horizontal tuning following inversion and the size of the inversion effect in the baseline condition were strongly correlated ($r = 0.564$, $p = 0.023$). Together, these results show that sensitivity to horizontal information in the face is associated with face identification performance, and supports the idea that a loss of this sensitivity following inversion underlies the face inversion effect.

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43.439 Don't look! Orienting to the eyes is not (entirely) under volitional control

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People look at eyes more than other facial features. What is unknown is if this bias is automatically or volitionally driven. We used a unique "Don't Look" paradigm to discriminate between these two alternatives. Participants were asked to freely view a series of faces or to avoid looking at either the eyes or the mouth of the faces. The free viewing data replicated previous results that people normally tend to fixate the eyes of faces. When asked to avoid looking at the eyes or the mouth of the faces, people were able to reduce fixations to the to-be-avoided feature, but they were less successful when asked to avoid looking at the eyes. These data demonstrate that looking at the eyes is not entirely under volitional control. In a second experiment, participants viewed inverted faces, which is known to disrupt face processing. Results again revealed a bias to look at the eyes during free viewing, but now when asked to avoid the eyes or the mouth, participants were equally successful at avoiding either feature. Thus, when normal face processing is impaired by inversion, attention to the eyes is under greater volitional control. Together, these data indicate that the preferential bias to attend to the eyes of upright faces reflects the combination of automatic and volitional processes. Our research also introduces the "Don't Look" paradigm as a simple and powerful paradigm for teasing apart the automatic and volitional processes that are contributing to a particular cognitive phenomenon.

Face perception: Neural mechanisms

Monday, May 9, 8:15 am - 12:15 pm

Orchid Ballroom, Poster Boards 440 - 455

43.440 Defining the fundamental stimulation frequency for individual face perception

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In a recent study, we showed that EEG power at a constant frequency of stimulation (3.5Hz) was much larger when different individual faces were presented compared to when the same face was presented repeatedly (Boremanse et al., *J Vis*, 2010 10(7): 564). This adaptation of the steady-state visual evoked potential response was localized on occipito-temporal sites, in particular over the right hemisphere. Here, we defined the suitable stimulation frequency ranges of this effect. Four observers were submitted to 81s sequences of faces presented at different rates (1Hz to 16Hz or faces/second; Figure 1) while high-density EEG (128 channels) was recorded. Fast-Fourier Transform (FFT) of EEG and computation of signal-to-noise ratio (SNR) showed a larger response to different faces than identical faces between 3Hz and 9Hz on occipito-temporal sites. In three observers, this difference had the form of a Gaussian curve that peaked at 6Hz (Figure 2), while in one observer the peak of maximal difference was at 4Hz. This observation indicates that individual faces are best discriminated perceptually when the face stimulation oscillates at 6Hz. Such a fundamental frequency rate should be used by future studies that aim to tag the sensitivity to individual faces in the human brain. Interestingly, at 6Hz it takes 160ms for the sinusoidal stimulation to complete a full cycle, and this time value coincides with the latency of the earliest face identity adaptation effect as found on the face-sensitive N170 component after flash stimulation (Jacques et al., *J Vis*, 2007). Hence, while the exact nature of the relation between the N170 and the phenomenon reported here in the frequency domain is still to be determined, our results support the view that the human brain requires about 160ms to process individual facial information efficiently.

43.441 Holistic perception of faces: direct evidence from frequency-tagging stimulation

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How does the visual system integrate object parts into coherent global visual representations? We investigated this question using faces, a category of stimuli which is perceived more holistically than other visual objects. Holistic face perception was tested by means of frequency-tagging (Regan & Heron, 1969). Participants saw a whole face whose left and right

halves flickered at different frequencies (at 4 or 5 Hz, counterbalanced across different stimulation blocks of 90 seconds). In two other conditions, the face halves were spatially separated by 0.29 or 1.74 visual degrees. Electroencephalogram (EEG) was recorded (128 channels) and transformed by means of Fast Fourier Transform (FFT). EEG signal showed posterior responses at fundamental frequencies of stimulation (4 and 5 Hz), and at several interaction terms (e.g., 4 + 5 = 9 Hz) at occipito-parieto-temporal sites, with a right hemisphere advantage. EEG power at fundamental frequencies increased significantly as soon as half faces were moved apart from each other, independently of the amount of spatial separation. Most interestingly, EEG power of the first order interaction term (9 Hz) showed the opposite pattern of behaviour than that of the fundamental frequencies, decreasing when the face halves were separated. To control for interpretation of the interaction term as reflecting a border effect, we conducted a second experiment with a condition in which half faces were vertically misaligned but shared the same amount of border as in the normal whole face condition. The results were replicated: increase of the fundamental frequencies and decrease of the first interaction term in the vertically misaligned condition. Overall, these results show that single face parts are less strongly represented when they are integrated into a coherent whole stimulus. Moreover, the presence and behaviour of interaction terms in the frequency-tagging method provide evidence for integration of facial parts into a holistic representation.

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43.442 Investigating the neural correlates of personally familiar face recognition using dynamic visual stimulation—an fMRI study

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Personally familiar face recognition is fast and extremely accurate despite large variations in viewing conditions, and thus available information. Notwithstanding considerable efforts, the neural correlates of this efficiency remain largely unspecified. Using a novel dynamic visual stimulation technique, we investigated the brain regions involved in perception and recognition of familiar faces encountered repeatedly in real-life (classmates) in an event-related fMRI experiment. Stimulation started with presentation of an average face containing only very low spatial frequency information (LSFI; 1.5 c/f), displayed for ~2500 msec (2TR). Then, incrementally increasing amounts of high spatial frequency information (HSFI; in steps of ¼ octave per TR; trial duration: 27TR) were provided to progressively and dynamically reveal personally familiar or unfamiliar faces. This slow presentation rate was used to decelerate the recognition process (e.g. James et al., 2000; Kleinschmidt et al., 2002; Sadr & Sinha, 2004; Carlson et al., 2006; Eger et al., 2007), and mimic a coarse-to-fine mode of visual perception (Sergent, 1986). In line with previous findings (Watier & Collin, 2009), familiar face decisions required less HSFI than unfamiliar face decisions. Region of interest analyses within regions comprising the “core system” of face perception (Haxby et al., 2000) revealed that responses in the FFA and STS—not OFA—were modulated by familiarity. Importantly, however, these areas required relatively more HSFI than several regions (face-preferential and non-preferential) identified in a whole brain analysis by contrasting un-/familiar sequences: the amygdala, and other areas of the medial temporal lobe in the right hemisphere (perirhinal cortex, hippocampus), which were not face-preferential. These results emphasize the importance of regions of the medial temporal lobe for familiar face recognition. In particular, they highlight the involvement of the amygdala, which required less HSFI information to categorize faces according to their familiarity, than those regions previously considered to comprise the “core system” of face perception.

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43.443 ERP evidence for the speed of face specificity in the human brain: disentangling the contribution of low-level cues and high-level face representations

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How fast are visual stimuli categorized as faces in the human brain? Because of their high temporal resolution and the possibility to record simultaneously from the entire system, electromagnetic (EEG, MEG) scalp measure-

ments seem to be the ideal method to clarify this issue. However, despite years of research, this question remains debated, with studies reporting face-sensitive responses on the scalp varying from 50 ms to 200 ms following stimulus onset. Here we disentangle the contribution of low-level properties and high-level visual representations in accounting for early face-sensitivity in the human brain, by means of a factorial paradigm including faces, familiar objects (cars) and their respective phase-scrambled counterparts. In fifteen human participants, we replicated an early face-sensitivity - larger amplitude to pictures of faces than cars - on the positive event-related potential (ERP) P1 (80-100 ms). However, this larger response to faces was accounted for completely by low-level parameters, the P1 being also larger in response to scrambled pictures of faces than scrambled cars. In contrast, the following visual responses (N1, or N70) reflected the brain response to meaningful shapes, being almost non-existent for scrambled stimuli. As usually observed, this N170 was larger in amplitude for pictures of faces than cars, especially in the right hemisphere. Contrary to the earlier P1 effect, this N170 face effect could not be explained at all by differential low-level parameters, the N170 amplitude to scrambled faces and cars being equal. Altogether, these observations indicate that the early visual potential P1 is determined by properties of the stimulus while the following N1 or N170 reflects what the observer perceives/interprets. Moreover, preferential responses to faces may arise at several points in time during visual stimulation, but the earliest access to high-level face representations does not precede the occipito-temporal N170 onset in the human brain.

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43.444 The localization and functional connectivity of face-selective regions in the human brain

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Neuroimaging studies have revealed a number of regions in the human brain that respond to faces. However, the way these regions are defined and how they interact is a matter of current debate. Here, we used fMRI to define face-selective regions in the human brain, and functional connectivity to determine how these regions interact. First, we compared the response to faces with the response to a range of non-face images. The pattern of selectivity across the brain varied for each contrast (face>bodies, face>objects, face>places, face>scrambled). Nevertheless, the core face regions in the occipital and temporal lobe (FFA, OFA, STS) all showed significant face selectivity, with a larger response to faces compared to each non-face image condition. Face-selectivity was also evident in other regions that have previously been incorporated into models of face processing, such as the amygdala, inferior frontal gyrus and intraparietal sulcus. However, we also found face-selectivity in the precuneus and superior colliculus. Next, we determined how the face-selective regions interact. We found significant correlations between the time-courses of the core face-selective regions (FFA, OFA, STS). To determine whether this coactivity between the core regions reflected functional connectivity, we removed the stimulus-driven component in each time-series. Although the non-stimulus driven time-courses in the OFA and FFA showed a significant face-selective correlation, we found no evidence for functional connectivity between the OFA and STS or between the FFA and STS. Interestingly, the connectivity between corresponding face regions in different hemispheres (e.g. rFFA-lFFA) were higher than between different core regions in the same hemisphere. These findings challenge models of face processing that propose the OFA projects to both the FFA and STS. These data also imply that inter-hemispheric connections between corresponding face-selective regions may play an important role in face processing.

43.445 Image-invariant neural responses to familiar and unfamiliar faces

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Introduction. The ability to recognize familiar faces across different viewing conditions contrasts with the inherent difficulty found in the perception of unfamiliar faces across similar image manipulations. We used fMR-adaptation to ask whether this difference in recognition might be reflected by an image-invariant representation for familiar faces and an image-dependent representation for unfamiliar faces in face-selective regions. Methods. In the first experiment, 20 participants were scanned while viewing images of faces in a blocked design. Each block contained 8 face images with the

same identity. There were 4 conditions: (1) 8 repetitions of the same face image, (2) 4 repetitions of 2 face images, (3) 2 repetitions of 4 face images, (4) 1 repetition of 8 face images. In the second experiment, we used the same design but the images were taken from different identities. fMRI responses were evaluated statistically in regions of interest that were identified independently by a localizer scan for each participant. Results. In the first experiment, we found a gradual release from adaptation in the FFA with increases in the number of face images within a block. For example, there was no significant difference between the response of the FFA to the repetition of the same face image and the response to 2 face images with the same identity. In contrast, in the second experiment, we found there was a complete release from adaptation in the FFA when 2, 4 or 8 face images with different identities were presented within a block. Conclusion. Although these results are consistent with an image-invariant representation of faces in the FFA, we found no difference in the pattern of response to familiar and unfamiliar faces. This suggests that differences in the perception of familiar and unfamiliar faces may not depend on differences in image invariance within regions such as the FFA.

Acknowledgement: Wellcome Trust

43.446 Sensitivity of human cortical face selective regions to face shape and texture

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Introduction. Our ability to recognize familiar faces depends more on texture (surface pigmentation) than shape (feature positioning) cues (Bruce et al., 1991; Burton et al., 2005). Accordingly, brain areas involved in processing facial identity should be more sensitive to changes in the texture of the face compared to changes in the shape of the face, and this difference should be more evident for familiar faces.

Methods. We used an fMRI adaptation paradigm to test the sensitivity of face selective regions in human visual cortex to variations in the shape or texture of familiar and unfamiliar faces. Twenty participants were scanned (3T GE Signa scanner) while viewing images of faces in a block design. A block consisted of 8 images of faces (either all familiar or all unfamiliar) presented in the following conditions: 1) same face image repeated; 2) 8 faces varying in shape only; 3) 8 faces varying in texture only; 4) 8 faces varying in both shape and texture. fMRI responses were evaluated statistically in regions of interest that were identified independently by a localiser scan for each participant.

Results. The fusiform face area (FFA) and occipital face area (OFA) showed strong adaptation to repeated images of the same face, consistent with previous results. However, both regions showed a similar release from adaptation to either shape or texture changes for both familiar and unfamiliar faces.

Conclusions. We find that the FFA and OFA are sensitive to both the shape and the texture of familiar and unfamiliar faces. These findings suggest that the responses of face selective regions (such as the FFA) are less invariant than current models imply.

References: Bruce V, et al. (1991) Recognising facial surfaces. *Perception* 20:755-69. Burton AM, et al. (2005) Robust representations for face recognition: The power of averages. *Cognitive Psychology* 51:256-84.

Acknowledgement: Wellcome Trust

43.447 Confounding of prototype and similarity effects in fMRI studies of face and object representation

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In separate neuroimaging studies, the effects of stimulus similarity and prototype representation have been sought in neural coding for faces and objects (e.g., Jiang et al., 2006, *Neuron*, 50, 159-172; Loffler et al., 2005, *Nat Neurosci*, 8, 1386-1390; Panis et al., 2010, *JOCN*). Stimulus similarity is characterized as a graded recovery from neural adaptation with ever greater dissimilarity between a pair of stimuli. A prototype effect, in contrast, is a larger absolute response to a stimulus which is distant from the center of a stimulus space. While intellectually distinct, these effects are highly confounded in measurement in standard neuroimaging paradigms and can be mistaken for one another. Stimuli which are more distinctive are less subject to adaptation from perceptual neighbors. Therefore, a putative

prototype effect may simply result from greater adaptation of prototypical stimuli by other stimuli in the experiment. Conversely, stimulus pairs which are the most perceptually distant from one another, and therefore expected to show the greatest recovery from adaptation, are disproportionately drawn from the extremes of the stimulus space. Therefore, a putative neural similarity effect may be created by an underlying prototype representation. In a standard design (5 morph levels and a target; event-related presentation) these effects can be 90% confounded. These effects may be dissociated properly in the context of a counter-balanced experimental design (e.g., continuous carry-over; Aguirre, 2007, *NeuroImage*). A linear model may then be used to estimate simultaneously the otherwise confounded effects of similarity and prototype. We will show how this may be done both with event-related potential (Kahn, Harris, Wolk, Aguirre, 2010, *JOV*) and fMRI data, and consider the interpretation of prior reports in the literature in light of these observations.

43.448 Face-likeness and variability drive responses in human face-selective regions

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fMRI research has identified regions in the human ventral visual stream that respond selectively to faces over objects. Although researchers typically use stimuli that are either clearly faces or clearly not faces, insights can be gained by examining responses to stimuli that fall in between these extremes. Here, we use parameterized face silhouettes to manipulate the perceived face-likeness of stimuli and measure responses in face- and object-selective ventral regions with high-resolution fMRI. Critically, we contrast two methods of defining blocks of silhouettes at different levels of face-likeness. In Study 1, we use "concentric hyper-sphere" (CH) sampling to define face silhouettes along 12 orthogonal dimensions of silhouette face space and block stimuli by their distance from the prototype face. Observers rate the stimuli as progressively more face-like the closer they are to the prototype. However, responses in face-selective regions paradoxically decrease as face-like ratings increase. A similar response profile is observed in object-selective regions. We hypothesize that this is because CH sampling produces blocks of stimuli whose variability is negatively correlated with face-likeness. As a consequence, responses in ventral regions are more adapted during high face-likeness (low-variability) blocks as compared to low face-likeness (high-variability) blocks. In Study 2, we test this prediction by generating matched-variability (MV) blocks of stimuli at the same distances from the prototype face as in Study 1. Under MV sampling, we find that responses in face-selective regions gradually increase with perceived face-likeness, whereas responses in object-selective regions are not modulated. Our studies provide novel evidence that face-selective responses track the perceived face-likeness of stimuli, but that this response profile is only revealed when image variability is matched across blocks. Because face- and object-selective regions are highly sensitive to image variability, future fMRI studies of face and object representation should strive to control image variability across conditions.

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43.449 Early species sensitivity of face and eye processing: an adaptation study

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The current study employed a rapid adaptation procedure to investigate the response profile of the early face-sensitive N170 ERP component to human and animal faces. Adaptors (S1) consisting of full faces, isolated eye regions and eyeless faces of humans, apes, dogs and cats were rapidly followed by a full human face as test stimulus (S2). All stimuli were equated in luminance, contrast and spatial frequencies. In response to adaptor stimuli (S1), human faces yielded significantly lower N170 amplitudes than human eyes, as classically reported, whereas no difference was found between animal eyes and faces. In response to S2 and in line with the adaptation mechanism, an attenuation of N170 amplitude was found for all types of face-related adaptors relative to house adaptors irrespective of species. Eye stimuli elicited stronger adaptation than face stimuli for humans, apes and cats, but not for dogs. These results support a differential role of eyes in early face processing for humans compared to animal species. Their significance is discussed in light of a recent model of face processing stipulating eye- and face-selective neuronal populations (Itier, 2007).

Acknowledgement: Canada Research Chair (CRC) program, Canadian Institutes for Health Research (CIHR), Canada Foundation for Innovation (CFI) and the Ontario Research Fund (ORF)

43.450 Multi-voxel pattern analysis of face and object exemplar discrimination in occipital cortex.

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Background: Face or object areas such as the fusiform face area (FFA), occipital face area (OFA), superior temporal sulcus (STS) and lateral occipital cortex (LOC) are typically determined in fMRI by subtractions showing higher activation for faces or objects than other stimuli. However, contrast analyses do not inform us about the functions of these areas, in particular in discriminating between different exemplars. Objective: We used multi-voxel-pattern analysis (MVPA) to determine whether spatial fMRI patterns discriminated between faces and objects, and between different exemplars of faces and objects in different regions. Methods: We used a localizer to identify the LOC, FFA, OFA and STS. In the experimental block subjects viewed two different faces and two different cars, chosen using an ideal observer analysis to equate physical differences between cars with those between faces. We used MVPA to determine discrimination accuracy based on activity in the top 200 voxels of each region. Results: All regions showed significant accuracy for between-category (car/face) discrimination and both within-category tasks (car1/car2, face1/face2). Between-category was better than within-category discrimination in right and left LOC and left FFA, but equivalent in all other regions. Accuracy for car exemplar discrimination was similar to face exemplar discrimination in all regions. Individual voxel weight magnitudes were positively correlated between car and face tasks in OFA and LOC, negatively correlated in STS, and not correlated in FFA. Conclusion: Better between-category discrimination is more typical of object processing in the LOC, but all core face regions and LOC may process the information necessary to individuate not just faces but also cars. Early processes common to both tasks may use overlapping neural populations giving rise to the positive correlations in OFA and LOC, which are not seen in FFA or STS, in which more specialized processes may recruit relatively distinct neural sub-populations.

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43.451 Differential selectivity for dynamic versus static information in face selective regions

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Neuroimaging studies have identified multiple face-selective regions in human cortex but the functional division of labor between these regions is not yet clear. A central hypothesis, with some empirical support, is that face-selective regions in the superior temporal sulcus (STS) are particularly responsive to dynamic information in faces, whereas the fusiform face area (FFA) is more sensitive to the static or invariant properties of faces. Here we quantitatively tested this hypothesis by measuring the magnitude of response in each region to both dynamic and static stimuli. Consistent with the hypothesis, we found that the right FFA and right occipital face area (OFA) responded similarly to movies of faces and to static images of faces from these same movies. By contrast the face-selective region in the right posterior STS (pSTS) responded nearly three times as strongly to dynamic faces as to static faces, and a face-selective region in the right anterior STS (aSTS) responded to dynamic faces only. Both of these regions also responded much more strongly to moving faces than moving bodies, indicating that they are engaged specifically in processing dynamic information from faces, not more generally in processing any dynamic social stimuli. A third face-selective region in the posterior-continuation of the STS (pcSTS) responded similarly to dynamic and static faces. The strong selectivity of face-selective regions in the pSTS and aSTS, but not the FFA, OFA or pcSTS, for dynamic information from faces demonstrates a clear functional dissociation between different face-selective regions, and provides further clues into their function.

Acknowledgement: BBSRC

43.452 Structural connectivity of face selective cortical regions with high definition fiber tracking

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Multiple brain areas are recruited during the perception of faces. However, the structural connections between the many functional areas that form the cortical network for face perception remain largely unknown. Here we use fMRI in conjunction with diffusion weighted imaging and deterministic fiber-tracking to investigate white matter connectivity between these functionally-defined visual areas. Face selective regions were identified using standard functional localizer scans contrasting faces to objects. The core set of regions of interest identified by this localizer included: the FFA (fusiform face area), the STS (superior temporal sulcus), aIT (anterior temporal lobe) and multiple OFA (occipital face area) regions. Subjects also participated in a diffusion spectrum imaging scan using a 257 direction sequence collected with a 32-channel head-coil, reconstructed using a generalized q-imaging method (Yeh, Wedeen, & Tseng, 2010). The functional regions of interest were then used as seeds for deterministic fiber-tracking to map the white matter connections between these visual areas. Connectivity was found between all of the OFA regions, FFA and aIT. Intriguingly, very little connectivity was identified between STS and other face selective regions, calling into question the role of the STS in static face processing. Finally, the multiple OFA regions identified with the functional localizer all showed connectivity to FFA, suggesting these neuroanatomically distinct posterior regions are subserving different functional roles within the face perception network. Our results provide a more complete map of the structural connectivity between functional areas of the face processing network and inform future studies of the specific functional roles of these brain regions.

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43.453 Scrambling horizontal face structure: behavioral and electrophysiological evidence for a tuning of visual face processing to horizontal information

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Recent psychophysical evidence indicates that a central feature of human face processing is its tuning to horizontally-oriented information. Specifically, filtering faces to remove all but the horizontal information largely preserves behavioral signatures of face-specific processing, including the face inversion effect (FIE). Conversely, preserving only vertical information abolishes these effects. The purpose of the present experiments was twofold. First, in contrast to previous studies which used filtering, we manipulated orientation content of face images by randomizing Fourier phase spectrum in a narrow horizontal orientation band (H-randomization) or vertical orientation band (V-randomization). Phase-randomization was performed on face images in which spatial frequency amplitude spectrum (SF-AS) was either left unaltered or equalized across all SF orientations. Second, we investigated the time course of tuning to horizontal information using event-related potentials (ERP). Picture-plane inversion was used to evaluate whether the effects of orientation of phase-randomization arise due to inherent stimulus properties or to face-specific perceptual biases. In two psychophysics experiments, we observed that (1) upright faces were best discriminated when the horizontal structure was preserved (i.e. V-randomization) compared to H-randomization. (2) This phase-randomization effect was eliminated by inversion, resulting in (3) a smaller FIE for H-randomized than V-randomized faces. Although this pattern was still present when SF-AS was equalized across SF orientations, it was less consistent, suggesting that SF-AS in horizontal orientation contributes to the horizontal tuning of face perception. Consistent ERP evidence of horizontal tuning for upright face processing was observed in the N170 time-window, a well-known face-sensitive electrophysiological component. The N170 was

delayed for H-randomized compared to V-randomized faces. Additionally, and in line with behavioural data, face inversion increased N170 latency to a smaller extent for H-randomized compared to V-randomized faces. Altogether, our findings indicate that horizontal tuning is a robust property of face perception that arises early in high-level visual cortex.

43.454 Frontal Lobe Involvement in Face Discrimination

Laura Cacciamani¹(lcacciam@email.arizona.edu), Mary A. Peterson¹; ¹University of Arizona

Evidence exists for a face processing network that includes areas of the frontal and temporal lobes. Temporal areas have been more widely studied in face perception; research on the frontal lobes has been mainly correlational. The current study aimed to investigate the role of frontal areas in face processing using behavioral experimental methodology. In Experiment 1, we used a face working memory (WM) load to overload the prefrontal cortex in healthy participants while they performed a same/different discrimination task on morphed faces and cars of varying difficulty. Results showed that on face discrimination trials, subjects made more false alarms (FAs) with versus without the face WM load, whereas car discrimination was unaffected ($p < .01$). This suggests that the resources needed for face discrimination may have been consumed by the face WM load. Experiment 2 took this one step further by investigating where these resources may be located. To eliminate the frontal memory component in Experiment 2, the faces held in memory in Experiment 1 were moved to the same screen as the discrimination task, thus serving as perceptual distractors. The results of Experiment 2 no longer showed more FAs on face compared to car trials ($p > .10$), which suggests that the difference in FAs between face and car trials found in Experiment 1 was due to the overload of frontal-dependent face discrimination resources by the face WM task. Additionally, the Experiment 2 results showed a significant decrease in hits on faces compared to cars when the distractors were present ($p < .01$), which we interpret as response interference. These results together are the first to experimentally implicate the frontal lobe in face perception. The question remains, however, whether this frontal involvement is specific to faces or if it is part of a general expertise network. A third experiment investigates this possibility.

43.455 Optimal eye-fixation positions for face perception: A combined ERP and eye-tracking study

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Previous research has outlined the existence of a saliency map among facial features, with the eye region being the most salient feature in a face. In addition, event-related potential (ERP) studies showed that the face-sensitive N170 component is larger in response to isolated eyes relative to other face features, and even to a whole face. Although these results suggest that the N170 could be mainly triggered by the eye-region, there is as yet no direct investigation of the N170 response profile when viewers fixate specific facial features within a whole face context. To address this question, EEG and eye-tracking measurements were recorded and monitored simultaneously to allow an accurate sampling of electrical brain signals from fixated face regions, while participants viewed faces in upright or inverted presentations. ERPs were averaged by gaze location (eyes, inion, eyebrows, nose, mouth and jaws). We also introduce a novel analysis procedure, neuroelectrical heat maps, that allowed mapping the amplitude of the N170 responses associated to specific eye-gaze fixations (measured by the eye-tracker) on face displays. Our results revealed that the optimal fixation position on an upright face (i.e., eliciting the largest N170s) is located around the nasion (triangle between two eyes and the upper ridge of the nose). Interestingly for inverted faces, the optimal positions are mainly clustered in the upper part of the visual field (around the mouth). Our results suggest that the N170 is not driven by the eyes per se, but could rather arise from a general perceptual setting (upper-visual field advantage). It is also possible that the upper part of faces (eyes) serves as an artificial horizon to align a face stimulus on a stored face template.

Tuesday Morning Talks

3D perception

Tuesday, May 10, 8:00 - 9:45 am

Talk Session, Royal Palm 1-3

Moderator: Andrew Welchman

51.11, 8:00 am

Spatial Interactions Enhance Stereoscopic Surface Discrimination

Christopher Tyler¹(cwt@ski.org); ¹Smith-Kettlewell Institute

Classic computational models of stereoscopic organization incorporate spatial interactions to help in solving the correspondence problem of stereoscopic surface reconstruction in complex cluttered scenes. To evaluate the role of such spatial interactions in human vision, we used a task of detecting the correlation state of a pair of stereoscopically defined patches in a field of dynamic random dots that either became binocularly correlated (BC) to form a surrounding surface of the same duration as the target patches or remained binocularly uncorrelated (BU) to form a field of incoherent depth continuous with the pre- and post-test intervals. The target patches could be both BC, both BU or a mixed pair; each patch being BC or BU with 50% probability. The observer had to indicate whether the targets had the same or different correlation states, requiring attention to both targets across space in order to perform the task. Target pairs in sets of four orientations were presented in either the presence or absence of a simultaneous surround plane. The effect of the target pair orientation was not significant. Performance as a function of target duration was best when the surround plane was presented, allowing discrimination of the joint target state in as little as 30 ms. Importantly, removal of the surround plane degraded performance by a factor of 5-10. The results indicate a substantial role of the simultaneous surround plane in solving the stereo correspondence problem, even though it was presented for only the very brief duration of the targets and could not therefore reduce the uncertainty of the target correlation state except through the spatial interactions that are the subject of the study. Our findings extend the BU/BC transition anisotropy of Julesz & Tyler (1976) to the domain of spatial integration and 3D attention in stereoscopic space.

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51.12, 8:15 am

Supra-threshold luminance and range discontinuities in natural scenes

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The statistical properties of image formation in the natural environment have been an important driving force of the evolution of biological vision systems. Luminance features in natural scenes have been studied extensively in recent years. In fact, the bandwidths, orientation tuning, and shapes of receptive fields are closely related to the spatial and spectral properties of natural luminance distributions. With recent advances and products based on light detection and ranging (lidar) technology, researchers have also begun to make progress on understanding the statistical properties of three dimensional visual features. We studied distributions of luminance, disparity, and range gradient magnitudes using a co-registered database of luminance and range natural images. We found that the 2D (luminance) and 3D (disparity or range) edge distributions can be well modeled as one-sided generalized Gaussian distributions with varying shape parameters. Through a simple thresholding process, we found that the probability of observing a strong luminance edge at supra-threshold 3D discontinuities is about 3 times greater than that of observing homogeneous luminance. Conversely, the probability of a strong, perceivable 3D edge at supra-threshold luminance discontinuities is about 5 times greater than that at homogeneous luminance regions. Interestingly, we also have observed a monotonic relationship between 3D gradient magnitudes and luminance gradient magnitudes at supra-threshold luminance discontinuities, suggesting that monocular luminance information may play a role in depth perception. However, we did not observe a clear dependency between the strength of luminance edges and the strength of 3D edges at

supra-threshold 3D discontinuities. We applied the statistical relationship between luminance gradient magnitudes and disparity gradient magnitudes in a Bayesian model of stereopsis. Direct comparison of the model's performance with and without the 2D-3D gradient dependency directly demonstrates the benefit of using these statistical relationships in recovering the 3D structure of the environment from 2D image data.

Acknowledgement: NSF

51.13, 8:30 am

Translating from local disparities to surface slant in the human visual cortex

Hiroshi Ban^{1,2}, James Blundell¹, Andrew E. Welchman¹; ¹School of Psychology, University of Birmingham, Birmingham, UK, ²Japan Society for the Promotion of Science, Tokyo, Japan

Responses to binocular disparity are widespread throughout the visual, temporal and parietal cortices. However, the circuits that transform local binocular disparities to coherent three-dimensional (3D) representations remain unknown. Here we use human fMRI to test for cortical areas that represent global 3D surfaces as opposed to local disparities. We measured fMRI responses while participants viewed random dot stereograms depicting slanted planes (± 7.5 to 52.5 deg in 15 deg steps). Using multi-voxel pattern classification analysis, we find that (i) slant can be decoded reliably across visual areas and (ii) there is pronounced fMRI pattern-tuning for slant in early visual (V1, V2) and dorsal (V3, V3A) areas. To determine whether this fMRI pattern information relates to surface slant per se or rather lower-level features (e.g. spatial extent or mean disparity of the stimuli), we measured responses when: (a) the spatial extent of the planes was fixed as slant was varied; (b) the mean disparity was fixed as slant was varied. We quantified the similarity between fMRI responses across conditions using a cross-correlation analysis. We find that fMRI responses in area V3A are highly similar when the same slant is depicted, irrespective of changes in spatial extent or overall disparity of the stimuli. However, this is not true in areas V1 and V2. Moreover, opposite slants evoke highly dissimilar responses in area V3A, while there is some similarity between responses in V1. Finally, training the classifier on data from the main experiment and testing on the control conditions (transfer test) demonstrates reduced decoding performance in V1 and V2. Together these results suggest V1 and V2 responses relate to low-level features (disparity-defined edges and distribution of disparities) while responses in V3A are compatible with the representation of surface slant.

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51.14, 8:45 am

Critical timing in combinations of stereo-disparity and shading

P. George Lovell¹(p.g.lovell@st-andrews.ac.uk), Marina Bloj², Julie Harris¹; ¹School of Psychology, St. Mary's College, University of St Andrews, ²Bradford School of Optometry and Vision Sciences, University of Bradford

Many cues have been shown to be optimally combined for depth perception, including, in our own hands, realistically rendered shading and binocular disparity. Almost no studies, however, have explored the timing of cue combination. We therefore do not know whether particular cues are processed faster than others when both are present in a stimulus.

Here we use cue-conflict stimuli with forward and backward masking to explore how temporal constraints influence the combination of monocular shading and stereo disparity cues. Accurately rendered stimuli, containing shape from shading and binocular disparity were created, depicting a pair of convex surfaces (scaled circular cosine in depth), presented side by side. Observers were asked to indicate whether the left or right convex surface stood out less in depth. By introducing a cue-conflict between the shading and disparity cues in one of the convexities, we were able to track the relationship between the point of subjective equality (PSE) and the extent of conflict between cues. At the shortest presentations (25 msec), PSEs were based upon the coarse shading cue. As presentation times increased there was a shift towards the slower, but more reliable stereo cue (stimulus durations > 100 msec).

In summary, we present the first evidence, from a cue-combination study, that supports the argument that shading cues alone can provide a quick-and-dirty estimate of depth and shape judgements. However, we also show that beyond around 100 msec, shading cues are vetoed in favour of the more reliable disparity cues.

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51.15, 9:00 am

Perception of Physical Stability of Asymmetrical Three-Dimensional Objects

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Visual estimation of object stability is an ecologically important judgment that allows observers to predict an object's physical behavior. One way to measure perceived stability is by estimating the 'critical angle' (relative to upright) at which an object is perceived to be equally likely to fall over versus return to its upright position. However, for asymmetrical objects, the critical angle varies with the direction in which the object is tilted. Here we ask: (1) Can observers reliably track the change in critical angle as a function of tilt direction? (2) How do observers visually estimate the overall stability of an object, given the different critical angles in various directions? Observers stereoscopically viewed a rendered scene containing a slanted conical frustum, with variable aspect ratio, sitting on a table. In Exp. 1, the object was placed near the edge of the table, and rotated through one of six angles relative to this edge. Observers adjusted its tilt angle (constrained to move directly toward the edge) in order to set the critical angle. We found that their settings tracked the variation in critical angle with tilt direction remarkably well. In Exp. 2, observers viewed on each trial one of the slanted frustums from Exp. 1, along with a cylindrical object of variable aspect ratio. They adjusted the aspect ratio of the cylinder in order to match the perceived stability of the slanted frustum. The results showed that on average observers' estimates of overall stability are well predicted by the minimum critical angle across all tilt directions, but not by the mean critical angle. Observers thus reasonably appear to use the critical angle in the least stable direction in order to estimate the overall stability of an asymmetrical object.

Acknowledgement: NSF CCF-0541185 and IGERT DGE-0549115

51.16, 9:15 am

3D Shape perception does not depend on symmetry

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Pizlo and colleagues have proposed an interesting new theory of 3D shape perception, in which the bilateral symmetry of objects is exploited to provide veridical estimates of 3D structure. They have also made a surprisingly bold assertion that accurate shape perception is only possible for objects that are symmetrical. The present study was designed to address two important questions related to these claims: First, are observers' judgments of symmetrical objects truly veridical, or are they subject to the same types of distortions that have been reported previously for the visual perception of 3D shape (e.g. Todd & Norman, 2003); and second, are shape judgments of symmetrical objects significantly more accurate than those obtained for asymmetrical objects? The stimuli consisted of randomly generated, smoothly curved, elongated objects whose orientations in depth were varied across trials. These objects could be either symmetrical or asymmetrical, and they were depicted with a mesh of contours that were arranged both radially and perpendicular to the axis of elongation. The observer's task on each trial was to adjust the orientation of a line to indicate the apparent slant of the object in depth. The results showed clearly that observers make systematic errors in judgements of object slant. Moreover, there were no detectable differences between the judgments obtained for symmetrical and asymmetrical objects. These findings indicate that several of the claims made by Pizlo and colleagues are greatly overstated. Although there may be a strong perceptual bias to prefer symmetrical over asymmetrical interpretations, we found no evidence to suggest that judgments of 3D shape are in anyway dependent or improved by a symmetry constraint.

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51.17, 9:30 am

Visuo-motor recalibration alters depth perception

Robert Volcic¹(robert.volcic@iit.it), Carlo Fantoni¹, Corrado Caudek^{1,2}, Fulvio Domini^{1,3}; ¹Center for Neuroscience and Cognitive Systems, Italian Institute of Technology, ²Department of Psychology, University of Florence, ³Department of Cognitive and Linguistic Sciences, Brown University

Relative depth from retinal disparities is overestimated at distances within the peripersonal space (where objects can be reached) and underestimated beyond the peripersonal space. This finding suggests that the extent of the peripersonal space may constrain the interpretation of retinal disparity. If this is the case then modifying the peripersonal space through visuo-motor recalibration should also modulate perceived depth from retinal disparities.

Participants performed a manual depth estimation task before and after visuo-motor recalibration. Visuo-motor recalibration was induced by displacing the visual feedback of the index finger in depth (15 cm). During the recalibration phase participants were required to repeatedly reach-to-point without haptic feedback to a vertical rod positioned at various distances within and beyond the peripersonal space. In the test phase, participants viewed a display composed of three vertical rods: one rod was positioned midway and in front of two flanking rods. Three depth separations were used between the central rod and the flanker rods, and this arrangement of rods was presented at three distances. Three-dimensional information was provided in a virtual environment by binocular disparities with consistent vergence and accommodation cues.

We found that visuo-motor recalibration strongly increased the estimates in the manual depth estimation task, coherently with the idea that the perceived depth is rescaled in accordance with an extended peripersonal space. Contrary to this result, the conflict between proprioceptive and visual cues in the recalibration phase should decrease perceived absolute distance. This would lead to an underestimation of the relative depth from retinal disparities. To test whether the effect we found in the manual depth estimation task is truly perceptual, participants also performed an open-loop reach-to-grasp task. Interestingly, in this motor task neither the grip aperture nor the final hand position were affected by recalibration revealing also a possible dissociation between reach-to-point and reach-to-grasp movements.

Eye Movements: Mechanisms, methods and models

Tuesday, May 10, 8:00 - 9:45 am

Talk Session, Royal Palm 4-5

Moderator: Therese Collins

51.21, 8:00 am

Effects of pupil size on recorded gaze position: a live comparison of two eyetracking systems

Jan Drewes¹(Jan.Drewes@cerco.ups-tlse.fr), Anna Montagnini², Guillaume S. Masson²; ¹Centre de Recherche Cerveau et Cognition (CerCo), UMR 5549 CNRS-UPS, Toulouse, ²Institut de Neurosciences Cognitives de la Méditerranée (INCM), UMR 6193 CNRS-Université de la Méditerranée, Marseille

Countless aspects of visual processing are reflected in eye movements and analyzing eye movements during visual stimulation has become the methodology of choice for many researchers in vision science and beyond. For decades, the scleral searchcoil technique has been considered the "gold standard" in terms of precision and signal to noise ratio, at the cost of pronounced setup overhead and a certain degree of invasiveness. On the other hand, camera-based eyetrackers are easy to use and non-invasive, yet, despite the dramatic improvement of the last generation systems, they have been known to be more noisy and less precise. Recently, a significant impact of changes in pupil size on the accuracy of camera-based eyetrackers during fixation has been reported (Wyatt 2010). We compared the accuracy and the pupil-size effect between a scleral searchcoil-based eyetracker (DNI) and an up-to-date infrared camera-based eyetracker (SR Research Eyelink 1000) by simultaneously recording human eye movements with both techniques. Between pupil-constricted (PC) vs. pupil-relaxed (PR) conditions we find a subject-specific shift in reported gaze position of up to >2 degrees with the camera based eyetracker, while the scleral searchcoil system simultaneously reported steady fixation, confirming that the actual point of fixation did not change during pupil constriction/relaxation. Individual repetitions

of 25-point calibration grids show the positional accuracy of the searchcoil system to be unaffected by pupil size (PC 0.52 +0.1 deg, PR 0.54+0.08 deg), whereas the camera-based system is much less accurate in the PR condition (PC 0.38 +0.12 deg, PR 0.98 +0.22 deg) due to increased pupil size variability. We show how these pupil-dependent shifts in recorded gaze position can affect the recorded dynamics of fixations (drift), saccades (reduced accuracy), pursuit (altered trajectory) and ocular following (directional bias), and we evaluate a dual-calibration-based method to compensate the pupil-based shift utilizing recorded pupil size.

Acknowledgement: CNRS

51.22, 8:15 am

Superior colliculus inactivation alters the influence of covert attention shifts on microsaccades

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Microsaccades are tiny saccades that take place during gaze fixation. Although long considered to occur randomly, recent evidence suggests that these movements are systematically biased by covert shifts of visual attention. Here, we show that superior colliculus (SC) activity is necessary for this influence of attention on microsaccades.

In 19 experiments, we reversibly inactivated SC neurons representing peripheral visual locations while two monkeys performed a demanding covert attention task. In this task, monkeys maintained fixation while four peripheral rings appeared in each visual quadrant. One of the rings was a different color from the others, serving as the attentional cue. Random dot motion patches (0% coherence) appeared inside each ring, and after some random delay, a brief coherent motion pulse occurred in the cued quadrant and in the diametrically opposite location (distractor). Monkeys had to report the direction of the cued pulse, irrespective of the distractor. We inactivated the SC with muscimol (see Lovejoy & Krauzlis, *Nature Neuroscience*, 2010) and compared microsaccade behavior before (baseline) and after inactivation.

When a cue guiding attention appeared in the peripheral visual region affected by SC inactivation, this cue's nominal influence in biasing microsaccade directions (confirmed from baseline data) disappeared. When the cue appeared in the region diametrically opposite from the affected area, its effectiveness in biasing microsaccade directions re-emerged. Importantly, these effects were not accompanied by a reduction in the overall microsaccade rate, suggesting that peripheral inactivation did not impair the motor control of microsaccades.

We conclude that SC activity is causally involved in the previously observed relationship between microsaccades and covert shifts of attention to peripheral locations. We hypothesize that biases in SC activity during attentional allocation normally alter the overall balance of SC activity representing the foveal fixated goal, in a manner sufficient to periodically trigger small saccades.

51.23, 8:30 am

The role of efference copy in saccadic adaptation

Thérèse Collins¹(collins.th@gmail.com), Joshua Wallman²; ¹Laboratoire Psychologie de la Perception, Université Paris Descartes & CNRS, ²Biology Department, City College of New York

When saccades systematically miss their visual target, their amplitude adjusts, causing the position errors to be progressively reduced. Conventionally, this adaptation is viewed as driven by retinal error (i.e. the distance between primary saccade endpoint and visual target). Implicitly, this view regards the variability in the saccade endpoint as motor noise. Recent work suggests that the oculomotor system is informed about where the eye lands; thus, not all "retinal error" is unexpected. The present study compared two error signals that may drive saccade adaptation: retinal error and prediction error (i.e. the difference between predicted and actual post-saccadic images). Participants made saccades to a visual target on two successive days. The first day, during saccade execution, the target was extinguished if the amplitude was smaller (or, in some experiments, greater) than the running median, thereby modifying the average retinal error participants experienced without moving the target during the saccade. On the second day, targets were extinguished at the start of saccades and turned back on at a position that reproduced the trial-by-trial retinal error recorded on the first day. Despite the retinal error in the first and second sessions having

been identical, adaptation proceeded approximately three times as rapidly during the second session, when the predicted target position had been changed, arguing that the eye knows where it lands and where it expects the target to be, and that deviations from this prediction drive saccade adaptation more strongly than retinal error alone.

51.24, 8:45 am

Saccades to moving targets are not influenced by the speed overestimation at low luminance

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Previous studies showed that moving objects appear faster at low luminance (Hammett et al 2007, Vaziri Pashkam & Cavanagh 2008) as a result of the longer motion trace (Vaziri Pashkam & Cavanagh 2008). Here we examine whether this faster perceived motion affects motor responses to the moving objects. We investigated saccadic eye movements to linearly translating random dot patterns. On each trial subjects were asked to compare the speed of a "target" random dot patterns to that of a "match" random dot pattern and make a saccade to the stimulus that they perceive to move faster. Stimuli were removed as soon as the subject initiated a saccade. The speed of the "target" and "match" were systematically varied to obtain the psychometric function of the subjects in the speed judgment task. In half of the experimental blocks both target and match were presented at high luminance. In the other half, the luminance of the match was reduced by covering half of the screen with 2.4 log unit neutral density filters. Subjects' saccade choices showed that they judged the low luminance stimuli to move faster than the high luminance one. However, the landing position of the saccades remained similar at high and low luminance: subjects did not overshoot the low-luminance target as might be expected from the increase in the perceived speed. We suggest that although motion blur contributes to perceived speed, it does not contribute to the speed information that influences motor reaction to moving targets. These results demonstrate a dissociation between perception and action in response to the speed of moving objects.

Acknowledgement: National Institute of Health

51.25, 9:00 am

Reconsidering Yarbus: Pattern classification cannot predict observer's task from scan paths

Michelle R Greene^{1,2}(m.greene@search.bwh.harvard.edu), Tommy Liu¹, Jeremy M Wolfe^{1,2}; ¹Brigham and Women's Hospital, ²Harvard Medical School

A very familiar illustration by Yarbus shows dramatic differences in eye movement patterns when a viewer performs different tasks while viewing the same image. The scan paths seem to be windows into the observer's mind but can the intentions of the viewer really be read from the pattern of eye movement. Yarbus' data are qualitative, drawn from only one observer examining one image. We showed 64 photographs to 16 observers for 10s each while eye movements were recorded and observers performed one of four tasks: memorize the picture, determine the decade in which the image was taken, determine how well people in the picture knew each other, or determine the wealth of the people. Eye movement data were fed into a pattern classifier to predict task, using leave-one-out training and testing. Although the classifier could identify the image at above chance levels (23% correct, chance=1.6%) as well as the observer (31% correct, chance=6.3%), it was at chance identifying the task (28% correct, chance=25% p=.49). Perhaps the earliest eye movements held the predictive information? Examining the first 2 and 5 seconds also yielded chance classification performance (27.4% and 27.7% correct). Perhaps more viewing would be more predictive? 16 additional participants viewed the images for 60 seconds each. Classifier performance remained at chance (28.1%). So, perhaps we built a bad classifier. Surely human observers can use observers' patterns of eye movements to predict task? 20 observers viewed another observer's eye movements, plotted over the image, and tried to predict which task was being done. Participants were at chance with either 10s (27.4%) or 60s (27.5%) scan paths. The famous Yarbus figure may be compelling but, sadly, its message appears to be misleading. Neither humans nor machines can use scan paths to identify the task of the viewer.

Acknowledgement: F32EY019815-01

51.26, 9:15 am

Cue Capture: When predictive cues hinder search performanceStephen C Mack¹(mack@psych.ucsb.edu), Sheng Zhang¹, Miguel P Eckstein¹;¹University of California-Santa Barbara

There is evidence that the presence of predictive cues typically improves performance in visual search tasks (e.g. Eckstein et al., 2000; Palmer et al., 2000). Here, we present a novel finding in which search performance was hindered by predictive cues at high signal contrasts. Method: Participants performed a visual search task in which they were to identify one of five letters (A-E) at one of five signal contrasts embedded in white noise. In cued trials, four colored circles were overlaid on the image with their colors indicative of how likely they were to contain the target (Red:40%, Green:20%, Blue:10%, Yellow:10%). The arrangement of the cued regions was arbitrary and identical across trials and participants. In the remaining 20% of trials, the target appeared outside of the cue circles. For uncued trials, stimuli were constructed identically (including the probabilistic structure of the target location) except for the absence of the circles. Results: Performance at low signal contrasts was higher for cued trials than uncued trials, mirroring traditional cueing effects. However, at high signal contrasts, observers achieved higher performance on uncued trials than cued trials. We suggest that these results arose from the overweighting of information at cued locations which impeded performance when targets were easily detectable. Behavioral results support this hypothesis, as performance for the 20% trials in which targets appeared outside the four probabilistically-defined cue areas was significantly lower for cued trials (circles present) than uncued trials (circles absent). Additionally, the frequency of eye movements towards high contrast targets appearing outside of the four probabilistically-defined cue areas sharply diminished when the cue circles were present. Conclusions: While observers often exploit predictive cues to enhance visual search performance, suboptimal overutilization of that statistical information in the guidance of saccadic eye movements can hinder performance when targets are easily detectable.

Acknowledgement: NSF-0819582

51.27, 9:30 am

Searching the horizon for small targetsAlbert Ahumada¹(al.ahumada@nasa.gov), Keith Billington², Jerry Kaiwi³; ¹NASA Ames Research Center, ²San Jose State University Foundation, ³U.S. Navy SPAWAR

We have simulated the search for small targets on the horizon using a display that has only a solid dark blue ocean below a solid light blue sky. The target is a single pixel the same color as the ocean in the sky adjacent to the ocean. Our goal was to model this one-dimensional search process. The first model we tried was random search constrained by an initial a priori distribution and no memory. This model predicts that the standard deviation of the number of fixations is about the same as the mean number of fixations, while the actual standard deviation was closer to the prediction of perfect memory. A simple model with a saccade-distance penalty and inhibition-of-return with a temporal decay was able to predict the first order distribution of saccades and the fixations standard deviation. However, when we looked at the distribution of saccades conditional on the location of the previous saccade we found that although most saccades continue in the same direction, there were a large number that went backwards and that the spatial distribution of these saccades showed no tendency to avoid the location of the previous fixation. Search models usually contain bottom-up processes, such as a saliency map, and top-down processes, such as a priori distributions over the possible locations to be searched. A situation that needs neither of these features is the search for a very small target near the horizon when the sky and the ocean are clear. How can search performance be lacking in memory (Horowitz & Wolfe, 1998, *Nature*), yet still have overall statistics that are so nearly optimal (Najemnik & Geisler, 2008, *J Vision*). We are now trying to find heuristic search strategies for this situation that have these properties.

Acknowledgement: NASA Space Human Factors Engineering and the Office of Naval Technology Capable Manpower Future Capabilities Program.

Binocular vision

Tuesday, May 10, 10:45 - 12:30 pm

Talk Session, Royal Palm 1-3

Moderator: Jenny Read

52.11, 10:45 am

The Spatiotemporal Limits of StereovisionKane David¹(davidkane@berkeley.edu), Guan Phillip², Hoffman David¹, Martin Banks³; ¹Vision Science, UC Berkeley, ²Joint Graduate Group in Bioengineering, UC Berkeley and UC San Francisco, ³Vision Science and Optometry, UC Berkeley

Sensitivity to luminance contrast varies with spatial and temporal frequency. Likewise, sensitivity to variations in binocular disparity also depends on spatiotemporal frequency. Disparity corrugations are visible only when their amplitude is between a lower and an upper limit. The lower limit reflects sensitivity to the smallest variation in disparity. The upper limit reflects the greatest change in disparity over space that can be perceived; this is the spatial disparity-gradient limit. We measured the spatiotemporal limits of stereopsis. In a 2-AFC task, observers discriminated between a sawtooth corrugation and a noise stimulus; the latter had the same distribution of disparities, but no spatial structure. We estimated the upper and lower amplitudes at which the sawtooth could be discriminated over a broad range of spatial (0.125-1.5cpd) and temporal frequencies (0-16Hz). We found that the lower limit is bandpass as a function of spatial frequency and lowpass as a function of temporal frequency. The lower limit is separable, which means that it can be described by the product of spatial- and temporal-frequency functions. For static gratings, we found that the upper limit is consistent with the spatial disparity-gradient limit. For moving corrugations of low spatial frequency, the upper limit is approximated by a temporal disparity-gradient limit. For other spatiotemporal frequencies, the upper limit is not described by a spatial or temporal gradient limit. Surprisingly, the upper limit is consistent with a spatiotemporal disparity-gradient limit (i.e., not exceeding a critical value in space-time). Unlike the lower limit, the upper limit is non-separable in spatial and temporal frequency. We show that non-separability is a consequence of a spatiotemporal gradient limit. The volume of spatial frequencies, temporal frequencies, and disparity amplitudes that are visible is quite constrained. Appreciating these constraints is important to the construction of effective stereoscopic imagery.

52.12, 11:00 am

Optimal disparity estimation in stereo-images of natural scenesJohannes Burge¹(jburge@mail.cps.utexas.edu), Wilson Geisler¹; ¹Center for Perceptual Systems, University of Texas, Austin

Many animals, including humans, have substantial binocular overlap within their visual field. In the binocular zone, each eye's viewpoint yields a slightly different image of the same part of the scene. Binocular disparity – the local differences between the images – is a powerful cue for estimating the depth structure of the scene. But before disparity can be used for depth estimation, disparity must be estimated from the images. Psychophysical, neurophysiological, and computational studies have discovered many of the computational principles, cellular mechanisms, and behavioral limits of disparity estimation. However, methods for optimally estimating disparity in natural stereo-images given a vision system's constraints remain to be determined. Here, we describe a principled procedure for determining how to optimally estimate disparity given a set of natural stereo-images, an inter-ocular separation, a wave-optics model of each eye, and two photo-sensor arrays. First, we randomly selected a large set of patches from well-focused natural stereo-images; all had disparities within Panum's fusional range (+30 arcmin). Next, we passed the images through each eye's optics. Then, we removed undetectable image detail as predicted by the human retinal contrast detection threshold. Finally, we used a task-focused Bayesian statistical learning method to discover the spatial filters that are optimal for estimating disparity in natural stereo-images. We found the filters to be spatial frequency bandpass, with characteristics similar to disparity sensitive receptive fields in early visual cortex. We used the filters to obtain unbiased, high-precision estimates of disparity in 0.5 deg (or smaller) natural stereo-image patches. The optimal filters and estimation performance provide rigorous benchmarks against which existing behavioral, neurophysiological, and computational results can be evaluated.

52.13, 11:15 am

Spatial stereoresolution for depth corrugations may be set in primary visual cortexFredrik Allenmark¹(fredrik.allenmark@ncl.ac.uk), Jenny Read¹; ¹Newcastle University, Newcastle upon Tyne, UK

Stereo depth perception has recently been modelled based on local cross-correlation between the left and the right eye's images. This model, which is based on the known physiology of primary visual cortex (V1), has successfully explained many aspects of stereo vision. In particular, it has explained the low spatial stereoresolution for sinusoidal depth corrugations (Banks et al, 2004; Filippini & Banks, 2009), suggesting that the limit on stereoresolution may be set in V1. In accordance with the properties of V1 neurons, the disparity detectors used in this model are tuned to locally uniform patches of disparity. Consequently, the model responds better to high amplitude square-wave corrugations than to high amplitude sine-waves, because the square-waves are locally flat while the sinusoidal corrugations are slanted almost everywhere and this slant is particularly large at large amplitudes. The model therefore predicts better performance at detecting square-wave than sine-wave disparity corrugations at high amplitudes. However, in contradiction with this prediction of the model we have recently shown that humans perform no better at detecting square-waves than sine-waves even at high amplitudes (Allenmark & Read, 2010). This failure of the model raised the question of whether stereoresolution is not set in V1 but at some later stage of cortical processing, for example involving neurons tuned to slant or curvature or whether a modified version of the model, incorporating more of the known physiology, may explain the new results with square-waves. We have tested a modified version of the local cross-correlation model which, based on psychophysical and physiological evidence that larger disparities are detected by neurons with larger receptive fields (a size-disparity correlation), uses larger windows to detect larger disparities. We show that the performance of this modified model is consistent with the human results, confirming that stereoresolution may indeed be limited by V1 receptive field sizes.

Acknowledgement: Royal Society, EPSRC

52.14, 11:30 am

Visual cortex responses to visual and electrical stimulations recorded by voltage sensitive dye imaging in cats and tree shrews.Christian Casanova^{1,2}(christian.casanova@umontreal.ca), Azaheh Naderiyanha¹, Matthieu Vanni¹; ¹School of Optometry, Université de Montréal, Canada, ²Institut de Génie Biomédical, Université de Montréal, Canada

It is well known that the primary visual cortex received its main thalamic drive from the lateral geniculate nucleus (LGN) through layer IV. In contrast, projections from the lateral posterior (LP) -pulvinar complex end for the most part in layer I, suggesting that LP-pulvinar exerts a diffuse modulatory influence on activity of the primary visual cortex. If that is the case, one would expect the spatio-temporal responses evoked by activation of these two pathways to be different. We investigated this issue by measuring the spatiotemporal dynamics of voltage sensitive dyes activation in the visual cortex following thalamic electrical stimulation in two different species: cats and tree shrews. Responses were compared to those evoked by visual stimuli (flashing squares and drifting gratings). Animals were anesthetized with halothane. RH1691 dye was used to stain the cortex. Stimulating electrodes were placed in the LGN and LP-pulvinar complex. Cortical responses evoked by flashing squares were observed in regions extending to several millimeters. At the activation site, positive responses were maximal at 90ms, while in surrounding regions, negative responses were observed (followed by activation). In cats, this profile was observed at the onset and offset of the square, while in tree shrew, it was only for the stimulus appearance. For gratings, orientation selectivity exhibited a tonic profile in cats, but a more transient one in tree shrews. Electrical stimulation of LGN induced a complex response comprising a fast positive component followed by a slow biphasic one. In surrounding and contralateral cortices, negative responses were observed, followed by activation. Electric stimulation of pulvinar did not induce any responses but strongly reduced the slow LGN-induced biphasic responses. In conclusion, stimulus inputs induce complex (species-selective) mechanisms of excitation/inhibition in time and space which involve cortical networks as well as thalamic modulation.

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52.15, 11:45 am

Experience-dependent plasticity in adult human visual cortex revealed by binocular rivalryClaudia Lunghi^{1,2}(claudia.lunghi@in.cnr.it), David Burr^{1,2}, Concetta Morrone^{3,4}; ¹Department of Psychology, Università Degli Studi di Firenze, Italy, ²Institute of Neuroscience, CNR – Pisa, Italy., ³Department of Physiological Sciences, Università di Pisa, Italy., ⁴Scientific Institute Stella Maris, Italy.

Neuroplasticity is a fundamental property of the developing mammalian visual system. A short period of abnormal visual experience during the critical period, such as occlusion of one eye, has dramatic and permanent neural consequences, reshaping visual cortical organization in favour of the non-deprived eye. After closure of the critical period, the brain is thought to be relatively hard-wired, with little or no experience-dependent plasticity. Using binocular rivalry – a sensitive probe of neural competition – we demonstrate that adult human visual cortex retains an unexpectedly high degree of neural plasticity, with important perceptual consequences. Following a brief (150 min) period of monocular deprivation, during which observers wore a translucent eyepatch on one eye, orthogonally oriented gratings (horizontal-vertical, S.F. 3 cpd, contrast 0.75) were presented separately to the two eyes through FE-Shuttering Goggles and observers reported their rivalrous visual perception by continuous keypress. Monocular deprivation strongly affected the dynamics of binocular rivalry, unexpectedly causing the deprived eye to dominate conscious perception twice as often as the non-deprived eye (mean phase duration of the deprived eye increased on average of the 53%, mean duration of the non deprived eye decreased on average of the 24%), and prevailing for as long as 90 minutes. Stimuli viewed by the deprived eye also appeared of higher contrast than those viewed by the other, as assessed by an apparent contrast matching procedure. We suggest that the deprivation acts by up-regulation of cortical gain-control mechanisms of the deprived eye, either by decreasing intracortical inhibition or increasing excitation. These results call for a reevaluation of adult visual cortical plasticity, fundamental to understanding how the adult visual system reacts to sensory loss, and for developing new therapeutic strategies that exploit the intrinsic plasticity of the visual cortex.

Acknowledgement: EC project

52.16, 12:00 pm

Human parietal cortex structure determines individual differences in perceptual rivalryRyota Kanai¹(r.kanai@ucl.ac.uk), David Carmel^{1,2,3}, Bahador Bahrami^{1,2,4}, Geraint Rees^{1,2}; ¹UCL Institute of Cognitive Neuroscience, University College London, UK., ²Wellcome Trust Centre for Neuroimaging, University College London, UK., ³Department of Psychology and Centre for Neural Science, New York University, ⁴Interacting Minds Project, Institute of Anthropology, Archaeology and Linguistics, Aarhus University and Centre of Functionally Integrative Neuroscience, Aarhus University Hospital, Denmark.

When visual input has conflicting interpretations, conscious perception may alternate spontaneously between them. There is a large amount of unexplained variability between individuals in the rate of perceptual switches. We investigated whether variability in perceptual rivalry is reflected in individual differences in brain structure. To do so, we collected perceptual switch rates for a structure-from-motion (SFM) stimulus from a group of 52 participants and examined whether variability in brain structure across participants could account for the individual differences in switch rate. We found that the gray matter volume of posterior superior parietal lobe (SPL) in both hemispheres correlated positively with inter-individual differences in switch rate, but an opposite relationship was found only in the anterior part of right SPL. Furthermore, causal influences of these areas on perceptual switch rate were confirmed using transcranial magnetic stimulation (TMS). Transient disruption of both left and right posterior SPL by TMS slowed switch rates, whereas disruption of right anterior SPL made the rate faster. These findings suggest that right anterior SPL is involved in maintenance of the current percept, while posterior SPL prompts switches to alternative percepts. The contrasting causal roles of the anterior and posterior parts of right SPL in perceptual rivalry suggest a functional fractionation of these regions in human right parietal cortex.

52.17, 12:15 pm

Predicting the conscious experience of other people

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There has been considerable interest recently in using multivariate decoding techniques applied to functional MRI signals in order to decode the contents of a person's consciousness. The use of such signals has inherent disadvantages due to the delay of the hemodynamic response. Moreover to date it has not been shown possible to generalize the decoding of brain signals from one individual to another. This limits the potential utility of such approaches. Here we used a different approach that circumvented these difficulties by using magnetoencephalographic (MEG) signals to decode the contents of consciousness, and to test whether such correlates generalized reliably across individuals. We used a 274 channel MEG system to record signals from 8 healthy participants while they viewed an intermittently presented binocular rivalry stimulus consisting of a face and a grating. Using a leave-one-out cross-validation procedure, we trained support vector machines on the MEG signals to decode the rivalry percept. Decoding was significantly better than chance in all participants. We then tested whether a support vector machine trained on MEG signals from one participant could successfully decode the rivalry percept of another. Again, decoding accuracy was significantly better than chance. These findings demonstrate that it is possible to decode perception independently of physical stimulation using MEG signals in near real time in a way that generalizes across individuals. Our findings indicate that there may be universal neural correlates of consciousness, and mark a potentially important step in the design of devices for decoding the contents of consciousness in individuals unable to report their experience behaviorally.

Acknowledgement: This work was supported by the Wellcome Trust (GR), the MindBridge project, the European Commission under the Sixth Framework Programme (BB), and the European Research Council (KS and MO).

Face perception: Cognitive factors

Tuesday, May 10, 10:45 - 12:30 pm

Talk Session, Royal Palm 4-5

Moderator: Jessica Taubert

52.21, 10:45 am

Observer- and stimulus-specific effects in unconscious evaluation of faces on social dimensions

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It has been proposed that two major axes, dominance and trustworthiness, characterise the social dimensions of face evaluation. Whether evaluation of faces on these social dimensions is restricted to conscious appraisal or happens at a preconscious level is unknown. If they exist, such pre-consciously perceived social labels might be entirely stimulus-specific, arising from physical characteristics of face structure. Alternatively, they may be interpretations arising from interactions between the stimuli and observer-specific traits. Monocularly viewed faces that varied independently along two social dimensions of trust and dominance were rendered invisible by continuous flash suppression (CFS) by presenting a flashing pattern to the other eye. Participants pressed a button as soon as they saw the face emerge from suppression to indicate whether the previously hidden face was located slightly to the left or right of central fixation. Time-to-emerge (T2E) was defined as the time taken for the face to emerge through CFS to be correctly localized. T2E was significantly longer for dominant and untrustworthy versus neutral faces. Two control experiments showed these findings were robust to face inversion and could not reflect delayed motor responses to conscious faces. These results demonstrate that evaluation of

social facial dimensions extends to a preconscious level and is stimulus-specific. We next investigated whether the variability in T2E across participants could be explained by personality traits. Participants completed 3 validated questionnaires: (1) a fear of negative evaluation" scale that quantified social anxiety; (2) a propensity to trust scale and (3) a submissive behaviour scale. The difference in T2E for untrustworthy versus neutral faces was negatively correlated with self-reported propensity to trust. In contrast, the difference in T2E for dominance versus neutral faces was positively correlated with submissive behaviour. We conclude that preconscious evaluation of social dimensions arises from interactions between stimulus features and observer-specific personality traits.

52.22, 11:00 am

Dynamic Cultural Representations of Facial Expressions of Emotion are not Universal

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Six 'universal' facial expressions - 'Happy,' 'Surprise,' 'Fear,' 'Disgust,' 'Anger,' and 'Sadness' - are defined by specific, static patterns of facial muscle activation (Facial Action Coding System codes, FACS). However, systematic differences in facial expression recognition between Western Caucasians (WC) and East Asians (EA) question the notion of universality, raising a new question: How do different cultures represent facial expressions? Here, we derived culture-specific models of facial expressions using state-of-the-art 4D imaging (dynamics of 3D face shape and texture) combined with reverse correlation techniques. Specifically, we modelled 41 core Action Units (AUs, groups of facial muscles) from certified FACS coders and parameterized each using 6 temporal parameters (peak amplitude; peak latency; onset latency; offset latency; acceleration; deceleration). The 41 AUs and their parameters formed the basis of a pseudo-random generative model of expressive signals. On each trial, we pseudo-randomly selected parametric values for each AU, producing an expressive facial animation (see Figure S1 in Supplementary Material). Ten WC and 10 EA naïve observers each categorized 9,600 such animations according to the 6 emotion categories listed above and rated the perceived intensity of the emotion (see Figure S1 in Supplementary Material). We then reverse correlated the dynamic properties of the AUs with the emotion categories they elicited, producing "dynamic classification models" (i.e., expected 4D face information) per emotion and observer. Analyses of the models reveal clear cultural contrasts in (a) the presence/absence of specific AUs predicting the reported EA miscategorizations and (b) radically different temporal dynamics of emotional expression whereby EA observers expect "smoother" emotional displays with lower acceleration and amplitude (see link in Supplementary Material for example videos). For the first time, we reveal cultural diversity in the dynamic signals representing each basic emotion, demonstrating that the complexities of emotion cannot adequately be reduced to a single set of static 'universal' signals.

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52.23, 11:15 am

Perception of health and facial attractiveness is influenced by small changes to lifestyle.

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Recent research demonstrates a marked influence of skin colour on facial appearance: enhanced skin redness and yellowness increases perceived healthiness and attractiveness. We have investigated the basis of skin colour associations with health, and examined the perceptual sensitivity to change in skin colour. Reduced blood oxygenation and skin perfusion occurs with cardiovascular disease but variation in a normal population is unclear. In 2 studies (n>50 young adult Caucasians) we found skin redness (CIE a*) was reduced in participants reporting mild illness (colds and flu) compared to those reporting no illness. Skin redness was also raised in participants reporting increased weekly exercise levels (even with modest amounts of extra exercise). In a study of 38 students, we found that skin yellowness (CIE b*) was associated with dietary intake of fruit and vegetables: increased consumption enhanced skin yellowness within 6 weeks.

We used a two-alternative forced choice paradigm to measure thresholds for change in apparent health and facial attractiveness due to change in skin colour. For colour changes associated with diet, thresholds were $\Delta E < 1.5$; equivalent to a change of 3.3 portions of fruit and vegetables per day. For skin colour changes with oxygenated blood perfusion, thresholds were $\Delta E < 1.4$; possibly equivalent to the difference between 0 and 1 hour of vigorous exercise a week. We conclude that even small changes to diet and lifestyle can induce perceivable benefits to skin colour, facial health and attractiveness.

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52.24, 11:30 am

Facial Expression Production and Training

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Research in facial expression production has shown that typical adults are adept at performing facial expressions spontaneously, but not voluntarily. The current study investigates the effects of training on facial expression production in typical individuals using the Computer Emotion Recognition Toolbox (CERT) (Bartlett, 2006). CERT is a video processing program that detects frontal-faces in a live video stream, and codes each frame with respect to 40 dimensions, including the 6 basic emotions and 30 facial action units (AU's) from the Facial Action Coding System (FACS) (Ekman & Friesen, 1978). FaceMaze is an interactive Pac-man-like game in which players navigate through a maze overcoming obstacles by producing facial expressions based on feedback from CERT. Experiment 1 consisted of two blocks, targeting Happy and Angry expression production exclusively. Participants were given a pre-training assessment in which emotion words were presented and participants were required to perform the matching facial expression. Electromyography (EMG) measures were recorded from the Zygomaticus Major (ZM), the Corrugator supercili (CS) and the Obicularis Occuli (OO) corresponding to the Happy, Angry and Surprise (control) expressions. Participants then played the FaceMaze game, followed by a post-training assessment that was identical to the pre-training assessment. Results revealed an improvement in expression production as indicated by post-FaceMaze increases in ZM and CS in the Happy and Angry block, respectively. In Experiment 2, naive participants were presented with videos of pre- and post-FaceMaze facial expressions and were asked to rate the video on the quality of the expression. Results showed that participants rated post-FaceMaze productions of the trained target expression reliably higher than pre-FaceMaze productions. In summary, the EMG findings from Experiment 1 and the expressions ratings from Experiment 2 support the use of CERT as a research and training tool in expression production and recognition.

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52.25, 11:45 am

When angry faces are just (a) cross

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Throughout man's time on Earth, one of the most consistent threats to his chances of survival has been other humans. It would seem, therefore, evolutionarily expedient to provide humans with every opportunity to detect the threat posed by individuals around them. Previous thinking along these lines has prompted some researchers to argue that certain facial expressions might be subject to enhanced processing to maximize the speed and accuracy with which humans locate individuals bearing threatening expressions. Evidence supporting this proposal comes largely from visual search tasks which have demonstrated that threatening expressions are more rapidly detected than non-threatening ones. An open criticism of this effect is that it may be due to low-level visual artifacts, rather than biological preparedness. One successful approach for controlling low-level, image-based differences has been to use schematic faces (simplified line drawings). We report experiments aimed at discovering whether the enhanced processing of threatening schematic faces, might also be due to low-level features within the stimuli. The first study replicated the standard threat search advantage, but also measured an effect using similar stimuli comprised

of obliquely oriented lines. The effect was also present with these stimuli rotated, a manipulation which served to remove any residual resemblance the abstract images had to a face. The results suggest that low-level features underlie the search advantage for angry, schematic faces, thereby undermining a key source of evidence of a search advantage for specific facial expressions. As an interesting aside: whatever the features happen to be, that are responsible for this effect, they are not captured in simple saliency models such as that of Itti & Koch (Vision Research, 2001).

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52.26, 12:00 pm

A General Recognition Theory Study of Race Adaptation

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Studies of race aftereffects show that adaptation biases responses away from an adapting stimulus. However, it remains unclear if shifts in response frequencies result from changes in perceptual representations or in decisional mechanisms supporting race classification. General recognition theory (GRT) provides a single modeling framework within which we investigated adaptation-induced changes on perceptual and decisional mechanisms. Phase 1 measured participants' white-black discrimination thresholds on facial feature and skin tone dimensions. Results were used to construct a two-dimensional stimulus set for a GRT experiment tailored to each participant's race thresholds. Phase 2 constituted a set of typical race adaptation tasks, in which participants made 2AFC (white, black) responses to faces varying on a single stimulus dimension (features, skin tone) under each of four adapting conditions (white/black features, light/dark skin tone). We replicated previous findings that adaptation shifts perceived features away from the adapting stimulus (adapting to white features made faces appear more black and vice versa), and we provide new skin tone adaptation results showing a similar effect on this dimension. Phase 3 included five tasks requiring complete identification (CI) feature and skin tone responses to four faces in feature-skin tone space (derived in Phase 1). The no-adaptation CI task provides participants' baseline models of perceptual race space, revealing positive correlations between features and skin tone within and across stimuli. As face features were perceived as more black (white), skin tone was perceived as darker (lighter). CI completed under the four adaptation conditions enabled modeling of adaptation-induced changes in participants' race space. Fitted models reveal shifts in perceptual representations away from adapting stimuli, variability in the within-stimulus correlations, and shifts in the decision bounds toward the adapting stimulus. Additionally, equal numbers of self-identified Caucasian and African-American subjects allow us to explore potential race group differences in adaptation aftereffects.

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52.27, 12:15 pm

The other "other-species" effect: Understanding important differences in primate face discrimination.

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As human adults, we find it difficult to discriminate between individual monkey faces. A sizable body of research attributes this "other-species effect" to insufficient experience. That is, our expertise with faces is limited to the species that we have been exposed to and have interacted with. In recent years, however, evidence has emerged to suggest that monkeys do not share this same expertise. Here, we advance our understanding of face discrimination in humans by comparing two nonhuman primate species using multiple markers of human face expertise. Chimpanzees (Pan troglodytes, N = 6) are our closest-living relative, and thus represent the most direct comparison for understanding human cognitive specializations. Rhesus monkeys (Macaca mulatta, N = 6) are more distantly related but more frequently used as neurological models of human face perception. All 12 subjects were born at the Yerkes National Primate Research Center (Atlanta, GA). Using a 2AFC MTS procedure we measured how face discrimination performance (% correct) in these two species was influenced by changes in orientation, viewpoint, geometric stretching, feature scrambling and contrast-reversal. We also tested whether the composite face effect was

contingent on contrast-polarity and sensitivity to first-order configurations in Mooney objects. Although these experiments reveal gross continuity across species they also point to a number of informative differences. For example, chimpanzees were more finely tuned to chimpanzee faces than monkeys to monkey faces. We conclude that while there is a common behavioural signature for face processing in both species, the data suggest that chimpanzees have an online face processing system, specialized for the subordinate-level classification of familiar faces. Monkeys, on the other hand, appear to process all faces uniformly. We propose that these differences across species (the other “other-species effect”) can be used to track the developmental origins of the face processing system in humans.

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Tuesday Morning Posters

Attention: Spatial selection and modulation

Tuesday, May 10, 8:15 am - 12:15 pm
Royal Palm 6-8, Poster Boards 301 - 329

53.301 Attentional selection of relative SF mediates global versus local processing: EEG evidence

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Previous research on functional hemispheric differences in visual processing has revealed a right hemisphere (RH) bias in global perception and a left hemisphere bias (LH) in local perception. Several theories of global versus local perception have proposed spatial frequency (SF) processing to underlie the hemispheric asymmetry. The Double Filtering by Frequency (DFF) theory proposed that visual attention selects and is directed to relatively low SFs by the RH and relatively high SFs by the LH, suggesting a direct causal relationship between SF selection and global versus local perception. We recently reported evidence in support of a flexible mechanism, based on relative SF, to underlie hemispheric asymmetry in global versus local perception (Flevaris, Bentin & Robertson, in press). However, the behavioral priming effects in the previous studies may have been observed due to a bi-directional additive model, in which the RH is biased towards relative LSFs and global objects whereas the LH is biased towards relative HSFs and local objects, rather than the DFF theory proposal, which is that selection of SF induces global/local processing. In the present experiment we examined the direction of modulation of responses in the two cerebral hemispheres by comparing activity in the EEG recorded at RH and LH sites while participants' attention was directed to global or local levels of processing after selection of relatively LSFs versus HSFs in a previous stimulus. Hemispheric asymmetry in the alpha band (8-12Hz) during preparation for global versus local processing was modulated by selected SF. In contrast, preparatory activity associated with selection of SF was not modulated by previously attended level (global/local). These results support the DFF theory that top-down attentional selection of SF mediates global and local processing and is not simply a bottom-up residual.

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53.302 Spatial attention affects perceived stimulus position

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Spatial attention can shift receptive field positions (Womelsdorf et al., 2006) and alter neural maps even in early visual areas (Fischer & Whitney, 2009). Here we report a shift in the perceived location of a peripheral stimulus when it is attended, but not when attention is continuously directed at fixation.

Two 3 x 0.5 deg vertical bars (100% contrast) were flashed (50 ms) in the right peripheral visual field (18 deg eccentricity), one above and one below the horizontal meridian, with variable Stimulus Onset Asynchrony (SOA). Subjects judged the horizontal location of the bottom bar relative to the top bar. When the bars were asynchronous, the second bar was perceived more to the right (more peripheral) than the first one by about 20% of the stimulus eccentricity. The size of perceived displacement increased with SOA up to about 250 ms and remained constant for all SOAs tested (up to 3.5 s). Crucially, the mislocalization effect vanished when spatial attention was drawn away from the stimuli. Attention was drawn away from the stimulus by adding a demanding primary task at fixation (reporting the sum of two digits flashed simultaneously with the peripheral stimuli). With attention drawn away, localization of the two peripheral stimuli appeared to be equal distances from fixation, regardless of their order of presentation. However, the localization bias reemerged when the primary task was moved to the location of the stimuli.

Our findings are consistent with the hypothesis that a covert shift of spatial attention causes distortions of visual space as a result of either shifting receptive fields of neurons that represent the attended location, or by a shift of perceived eye position.

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53.303 Independent effects of adaptation and attention on speed perception

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Introduction: Both attention and adaptation influence perception of visual stimuli. Adaptation typically causes a repulsive shift in perception of a given feature away from the adaptor, i.e., either an over- or underestimation, by shifting neuronal population activity away from the adaptor value. Spatial attention leads to an overestimation of several visual features, including motion speed (e.g., Turatto et al., 2007). This effect may similarly be caused by a shift in neuronal population activity. If a common neuronal population mediates both effects, adaptation and attention should interact. The magnitude and direction of the interaction should depend on the specific value of the adaptor: Attention and fast adaptor speeds have opposing effects on perceived speed and should thus counteract. Slow adaptor speeds often only have a weak effect and thus should not modulate the effect of attention. Methods: Here, we combine spatial attention and adaptation in a psychophysical paradigm. An uninformative, exogenous cue directed covert spatial attention to one of two moving stimuli. Observers reported which one they perceived as moving faster. Either the attended or the unattended stimulus was preceded by an adaptor moving at one of two speeds, slow or fast. Both speeds were chosen so that the fast adaptor yielded a strong adaptation effect, whereas the slow adaptor served as a control condition. We measured the point of subjective equality (PSE) for perceived speed. Results & Conclusions: Peripheral cueing shifted the PSE compared to neutral cueing consistent with an increase in perceived speed. This effect of attention, however, did not depend on the adaptation speed. In additional experiments, both the effect of attention and the effect of adaptation on perceived speed were found to be of similar magnitude when tested in isolation and when tested in combination. These results suggest that attention and adaptation affect perceived speed independently.

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53.304 The attentional repulsion effect distorts space but not objects

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The Attentional Repulsion Effect (ARE) is a spatial consequence of allocating attention to peripheral locations. Specifically, a reflexive shift of attention to the periphery creates an error in the localization of visual stimuli in the direction opposite to the shift. Thus, the ARE appears to be a location-based effect involving the dorsal stream of visual processing. While the ARE is one of the few known spatial consequences of orienting attention, a great deal is known regarding the temporal consequences of shifting attention. In this reaction-time based literature, it is well-documented that there are both location- and object-based components associated in the allocation of attention (e.g., Egly rectangles paradigm, inhibition of return). Given that these two components are often found in temporal measures of attention, the goal of the present three experiments is to determine if the ARE can distort the perception of both spatial locations and the shape of objects. Experiment 1 used a central diamond shape with circles at the top and bottom vertices, and subjects were instructed to focus on the shape of the whole diamond or the locations of the two circles. In Experiment 2 a classic Vernier task served as the location condition, while connecting the Vernier to form a solid line constituted the object condition. Experiment 3 entailed viewing a central diamond shape once again, with the distinction from Experiment 1 being that subjects did not have to make an instantaneous decision; rather a response screen was used to assess subjects' memorized perception of the target. All three experiments produced robust loca-

tion-based AREs, but no object-based AREs. These findings suggest that the ARE, unlike many temporal consequences of shifting attention, does not have an object-based component.

53.305 Competition limits spatial selection

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Comparing, tracking, or monitoring multiple objects may require that we select multiple spatial locations simultaneously. Previous studies show that this ability is possible for at least 2 and possibly up to 8 locations. What is the limited resource that determines these upper limits? We suggest that this independent resource is competition for space itself. Because selected locations are known to have suppressive surrounds, then if these surrounds have a minimum size, as selected locations become too close together in space they will compete and cause interference. The hemifield and quadrant boundaries may buffer this effect by blocking this competition, potentially explaining past results where these regions appear to have 'independent selection resources'. This competition account makes a unique prediction that a more general resource account does not - that even within a single visual quadrant, decreasing the distance between two selection regions should impair performance. We asked participants to monitor a stream of letters (180ms/letter) and to determine whether letters in two locations were the same or different. To ensure that participants selected only the relevant locations, letters were flanked by distractor letters. When these locations spaced far apart within a quadrant, performance was higher (70%) than when they were placed closer together (60%). Placing the letter streams across the hemifield boundary eliminated this proximity effect, such that performance was equally high at both distances (76%). Our results are consistent with a mechanism of selection that is limited by competition for selection within a spatiotopic map. We will also briefly discuss new work showing that these same limits on selection within static displays can also explain limits on selection in moving displays (multiple object tracking tasks).

53.306 Low level perceptual, not attentional, processes modulate distractor interference in high perceptual load displays: evidence from neglect patients

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According to perceptual load theory (Lavie, 2005) distractor interference is determined by the availability of attentional resources. If target processing does not exhaust resources (low perceptual load) distractor processing will take place resulting with interference. Only when target processing uses-up attentional capacity (high perceptual load) interference can be avoided. As such, the theory stresses attentional factors (availability of attentional resources) in determining distractor interference. An alternative account (Dilution, Tsai & Benoni, 2010) suggests that perceptual load effects might be explained by the mere presence of additional neutral items in high load displays (which typically involve set-size manipulation). These additional elements (as long as they have similar features as the distractor) may dilute the perceptual weight of distractor features. Accordingly, in displays with neutral items (similar to high load displays) but with easily discriminable targets (similar to low load displays) distractor interference is eliminated (Tsai & Benoni, 2010). Thus, dilution stresses low level perceptual factors as determining distractor interference in set size manipulations. One potential limitation of the dilution account is that even when targets are easily distinguished, attention might still be drawn to the neutral elements - consequently depleting resources so that distractor processing is prevented. To address this possible explanation we have tested a group of unilateral neglect patients. In neglect, low level perceptual processes are thought to be intact in the contralesional side while attentional capacity is damaged. Thus, by presenting neutral elements to the neglected side we were able to assess whether attentional or perceptual factors determine distractor interference. Our results indicate elimination of distractor interference when neutral elements are presented to the neglected side. We conclude that low level perceptual processes (rather than attention) underlie elimination of distractor interference in set size manipulation.

53.307 The Distribution of Attention in the Visual Field Under Perceptual Load

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The perceptual load theory of attention proposes that the degree to which visual distractors are processed is a function of the perceptual demands of a task - greater perceptual demands result in increased distractor filtering. Here, we used steady-state visual evoked potentials (SSVEPs) to investigate the distribution of load-induced attentional filtering across the visual field. Electroencephalogram (EEG) was recorded while subjects performed a foveal go-nogo task under two levels of perceptual load. Task stimuli were rectangles that varied in color (black or white) and orientation (vertical or horizontal) and subjects were assigned two such rectangles as targets. Perceptual load was manipulated between blocks by assigning targets that could be discriminated on the basis of color alone (low load) or a conjunction of color and orientation (high load). The effect of load on the distribution of attention was assessed by presenting a contrast reversing ring at one of three eccentricities (2°, 6°, or 11°) during performance of the go-nogo task. Rings contrast reversed at 8.3 Hz, providing an EEG frequency-domain signature that could be used to track changes in visual processing as a result of perceptual load. Results showed that power at the 8.3 Hz frequency was reduced under high perceptual load (relative to low load) but only at the 2° eccentricity. These results suggest that perceptual load does not modulate visual processing equally across the entire visual field but primarily filters visual stimuli most proximal to task-relevant stimuli.

53.308 Learning to Ignore Distraction: Training and Transfer

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Effective information filtering is an essential component of goal directed behavior. Our ability to selectively choose what information we attend to allows us to successfully perform a given task. Though attentional selection is not unique to the visual domain, the effective allocation of visual attention is important in our lives. Traditionally, training of visual attention has shown to be highly specific to the trained task or trained stimuli. However, recent research has shown that, with training, individuals are able to improve their ability to filter out distracting task-irrelevant images while performing a primary color discrimination task. Furthermore, when the trained distractor images are highly variable and dissimilar, individuals showed a greater ability to effectively filter distracting information at novel, untrained locations providing some evidence for transfer of training (Kelley & Yantis, 2009). However, it is unclear how broadly the previously observed attention training may transfer beyond the trained task. To explore this issue we had participants complete two sessions of training on a color discrimination task: one session with and one session without highly variable distractor images. In addition, participants also completed a number of cognitive tasks both before and after training to assess breadth of transfer. Consistent with previous findings, participants were able to overcome distraction related performance decrements and apply this generalized filtering mechanism to previously unseen distractor locations in the context of the same task. In addition, differential training benefits were observed at transfer to unrelated cognitive tasks including a simple reaction time task (31 ms reduction vs. 8 ms for controls) and a Stroop task (63 ms RT reduction vs. 20 ms for controls). These findings have positive implications for individuals' ability to effectively train visual attention and information selection processes to provide benefits extending beyond the trained task itself.

53.309 Selective attention and contrast gain control

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We investigated how selective attention to a target embedded in a textured background interacts with contrast gain control. Observers attended to an eccentric target surrounded by a concentric annulus that was either coextensive with the target (unsegmented) or segmented from it by the introduction of a small gap, or phase offset. A brief contrast increment appeared on the target on 50% of the trials. Because contrast gain control is phase insensitive, it predicts the same modulation of the surround whether it is in-phase or out-of-phase with the target. However, selective attention predicts that the surround will be more suppressed in the unsegmented condi-

tion, resulting in a smaller response at the surround frequency. We used steady state visual evoked potentials (SSVEP) with target and background tagged with different frequencies, to unambiguously monitor the response from target and background. For each observer we collected high-density EEG data from increment-absent trials ($n=7$). We then used a minimum norm inverse procedure combined with realistic MR-derived head models and retinotopically-mapped visual areas to estimate cortical activities for target and background. Our preliminary data suggests that the response in primary visual cortex to the surround that is in phase with the target is more suppressed than the surround that is out-of-phase. This finding argues against a purely contrast normalization account of the data. At the same time, the responses evoked by the target remained unchanged across the different conditions. These results suggest that selective attention may involve an active suppression of textured backgrounds that are co-extensive with the target.

53.310 The distribution of visuospatial attention is influenced by illusory differences in the size of physically identical objects

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According to the zoom-lens model (Eriksen & Yeh, 1985), the focus of attention (FOA) is adjusted in spatial extent to match the visual angle subtended by attended object(s), with a trade-off between the size of the FOA and the concentration of attention: the larger the FOA, the greater the diffusion of attention and the weaker its effects. Consistent with this trade-off, when informative spatial cues (e.g., squares) of different sizes are presented prior to target onset, RT is faster for small vs. large cues (Castiello & Umiltà, 1992; Turatto et al., 2000). It remains unclear, however, whether the size of the FOA is necessarily determined by the physical extent of the attended stimulus, and whether the relationship between the size of the FOA and the concentration of attention is fixed. We investigated these issues by presenting spatial cues that were perceptually different in size despite being physically identical. When the cues were superimposed on a simple line version of the Ponzo illusion, RT was reliably longer to targets appearing within the perceptually larger cue. This effect was replicated when cues were superimposed on a realistic, natural scene that induced the Ponzo illusion. This finding suggests either (a) that the size of the FOA is modulated by the perceived size of the attended object, or (b) that the size of the FOA is locked to the physical size of the object, but the concentration of attention is influenced by the perceived size of the object. Both possible accounts suggest specific ways in which current models of attention will need to be refined.

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53.311 Conjunction search without target-specific bias: An eye movement study

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We examined the effect of varying the distractor ratio on behavioural performance and eye movements during search for two possible conjunctive targets defined by differences in color and orientation that were matched for saliency. As in previous studies, search was facilitated and there were increases in fixations towards the target when unequal groups of distractors were presented – eye movements were also directed towards the minority subset of distractors sharing either the colour or orientation with the target. However, it was clear that first fixations were not positioned directly towards display stimuli, suggesting that items were processed in parallel rather than serially, with subsequent fixations becoming more accurate in their positioning. Fixations were directed more towards the centre of smaller colour groups whether they contained the target or not, with no similar bias for items with the same orientation. These data suggest that small groups defined by colour are selected together, with search remaining within the selected group when it contained the target (signalled by a local orientation disparity) or shifted to the larger colour group when the target was not present in the smaller color group. The results point to differences in color- and orientation-grouping in conjunction search.

53.312 Learning where to attend: Priming of pop-out drives target selection

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What we attend to is determined not only by salience and top-down guidance but also by what we have recently attended to. Covert orienting in singleton visual search tasks is faster when a previous search target repeats than when it changes, an effect called priming of pop-out (PoP). While many studies have investigated the characteristics of this form of priming and the mechanisms underlying it, much less is known about the potential usefulness of PoP in determining priorities in attentional selection without a designated target. Our aim was to examine whether priming in visual search plays a role in determining what objects or features we attend to when given a free choice. In a novel procedure we intermixed pop-out trials (one oddball target paired with two identical distractors) with free-choice trials (one object of each kind where neither pops out among distractors) where observers freely chose an object to attend to. Pop-out trials tended to drive subsequent choice, with observers typically choosing the preceding pop-out target. The strength of this effect steadily grew over successive pop-out trials with the same target, such that by six repetitions of the same pop-out target subsequent target choice was determined almost completely. In a second experiment we found that choice trials affected subsequent pop-out response times as strongly as did conventional PoP, indicating full priming build-up from free selection without actual pop-out. Our results support accounts of PoP centered on altered target priority and demonstrate the potent role PoP can play in guiding visual exploration.

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53.313 The modulation of spatial attention by exogenous cues in visual line bisection: Effects of cue-line SOA, cue contrast and cue position

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Neurologically normal subjects exhibit a systematic leftward error in estimating the midpoint (PSE) of horizontal lines (Jewell & McCourt, 2000). This tonic leftward error (pseudoneglect) reveals a contralateral bias in the deployment of visuospatial attention by the dominant (right) hemisphere, and is observed in both egocentric and allocentric (object-referenced) coordinate systems. Transient exogenous visual cues automatically recruit spatial attention to cued locations and phasically modulate tonic line bisection error (McCourt, Garlinghouse & Reuter-Lorenz, 2005). However, the optimal cue-line onset asynchrony (SOA), the cue-contrast response of this phasic cueing effect, and the relative effectiveness of cue locations relative to line endpoints are unknown. We report three experiments where subjects performed a tachistoscopic visual line bisection task (McCourt & Olafson, 1997). Pretransected lines ($27^\circ \times 3^\circ$, 150 ms) were preceded by cues delivered to the left and right line ends at a variety of contrasts, positions and stimulus onset asynchronies (SOAs). Cues were circular cosine gratings (3° diameter, 3 c/d, variable contrast, 30 ms duration). Experiment 1 manipulated cue-line SOA (40-500 ms). Optimal SOA was 90 ms, and there was no evidence for inhibition of return. Experiment 2 manipulated cue contrast (0.4-100%). Cue contrasts below 12% were ineffective in modulating PSE, and the maximal effect occurred for cues of 100% contrast. Experiment 3 manipulated the azimuthal location of the cue relative to the line endpoints (8 locations, varying from completely beyond the line endpoints to near line center). Cues at all spatial locations except the one lying completely beyond the line endpoints resulted in significant modulation of PSE. These results suggest that the mechanisms subserving exogenous cueing effects in line bisection have low contrast gain, and that cues exert their effects in an object-referenced coordinate system.

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53.314 **Detecting goal-relevant events boosts activity in primary visual cortex**

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Several recent behavioral studies suggest that target detection triggers more than an attentional response to the target itself. Rather, it appears that perceptual processing of information that is presented at the same time as a target is enhanced. To test this possibility, we used fMRI to measure how activity in visual cortical areas is modulated by the presence of auditory targets and task-relevant visual images. Participants were asked to perform two tasks at the same time: encode centrally presented images of faces and scenes into memory for a later memory test, and press the button whenever a beep of a certain frequency (target beep) is played over the headphones (no response was made when a distractor beep of a different frequency was played). Activity in V1 increased more when visual images were presented at the same time as target beeps than when they were presented at the same time as distractor beeps. Surprisingly, V1 responded more to auditory targets than to auditory distractors even when no images were presented. This increase in activity was observed in all of V1, including parts representing peripheral portions of the visual field. However, the increase appeared to diminish in higher visual areas such as the fusiform gyrus and the parahippocampal gyrus. A second experiment confirmed that the greater response of V1 to targets than to distractors is not due to cross-modal interactions between auditory and visual cortices. In line with several recent reports, it appears that activity in primary visual cortex reflects more than visual input and attentional selection processes. Instead, our data suggest that primary visual cortex is additionally sensitive to the need to make a cognitive or motor response to goal-relevant events.

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53.315 **Is there predictive remapping of visual attention across eye movements?**

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Visual information is primarily mapped in an eye-centered, retinotopic frame of reference. Because each saccade results in a shift of images on the retina, however, purely retinotopic representations cannot support the tracking of visual objects across saccades. The visual system therefore must compensate for the changing retinotopic locations of visual objects by updating their world-centered, spatiotopic information around the time each saccade is executed. In a series of experiments, we investigated how spatial attention is deployed to visual onsets during this updating period. If the focus of attention is updated rapidly in anticipation of an impending saccade, the spatiotopic coordinates of onsets may be transferred into "future-retinotopic" coordinates, thus facilitating target identification at two discrete locations. We tracked observers' eyes as they executed saccades to a cued location and made a manual response to a visual probe. Within 200ms of the saccade target appearing, a brief visual onset cue was displayed, followed by the target probe (a tilted bar). After completing the saccade observers were required to respond as quickly as possible to the orientation of the target. The cue was non-predictive of target location and, importantly, targets could be presented at one of three locations: the spatiotopic location of the cue, the future-retinotopic location of the cue, or directly between these locations. We found that the cue yielded faster responses to targets presented at the spatiotopic cue location, future-retinotopic cue location, and between these locations, when compared with eccentricity-matched control locations. These findings are contrary to the notion that the focus of attention shifts to the future location of attended objects just prior to a saccade. Our results also challenge the hypothesis that attention shifts predictively prior to saccades in an analogous way to neurons that predictively shift their receptive-fields.

53.316 **Asymmetric alpha desynchronization during the maintenance of spatial attention**

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In electrophysiological studies, persistent desynchronization in the alpha (8-12 Hz) frequency band has been considered to be a signature of maintenance of spatial information. However, simple comparisons between contralateral and ipsilateral representations fail to explain the detailed profile of the spatial representation in attentional control, particularly hemispheric asymmetry indicated in hemineglect patients. Here, we tested the hypothesis that attention modulates neural oscillation in a spatially selective manner. Using magnetoencephalography (MEG), we measured the alpha power while subjects' attention was endogenously oriented to the peripheral visual field. We found posterior alpha desynchronization in sensors contralateral to the attended visual field. This desynchronization and spatial selectivity persisted throughout the delay period. These findings suggest that spatial attention modulates neural synchrony in a spatially biased manner. The decrease in alpha synchronization may cause the excitation of the task-related cortical regions for enhanced visual information processing. Moreover, we found that the left sensors showed greater contralateral bias than the right sensors in the lower alpha band. This is consistent with the theory that the right parietal cortex represents both visual fields, whereas the left parietal cortex predominantly represents the right visual field. The asymmetry in the neural oscillatory pattern offers an indication for the neural mechanism that underlies the hemineglect symptoms observed after right hemisphere lesions.

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53.317 **The influence of target-distractor similarity on perceptual distraction**

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According to the Load theory of attention, the perceptual processing of irrelevant information is determined automatically in response to the perceptual demands of processing task-relevant information (e.g. Lavie, 1995; Lavie, Hirst, De Fockert, & Viding, 2004). Because of the assumption of automaticity, increases in perceptual load should reduce task-irrelevant processing irrespective of the distractor-target relationship. While research has supported the modulation of distraction as a function of perceptual load (Lavie, Hirst, DeFockert, & Viding, 2004; Wei, & Zhou, 2006), tests of task-irrelevant processing have typically confounded the relative influence of target-distractor similarity on multiple dimensions (i.e., feature and response compatibility). The purpose of the present experiment was to isolate the relative contribution of these factors. Participants (n=17) were instructed to identify the category of a centrally presented stimulus ('d' or 'q') while ignoring irrelevant flankers presented in the periphery. There were two key manipulations: 1) target-distractor relationship was manipulated such that distractors can share neither feature nor response ('S' or 'G'), share only features ('b' or 'p'), share only responses ('Q' or 'D'), or share both feature and response ('d' or 'q') with the target and 2) load was manipulated by incrementally shifting the 'o' target feature vertically making the stimulus category more or less ambiguous. The results indicated that performance was modulated by the target-distractor relationship even under conditions of high perceptual load. Thus, these results support the conclusion that perceptual load is not the only determinant of the behavioral interference caused by task-irrelevant information, but rather that the amount of distraction is also influenced by the degree to which task-irrelevant information matches one's current attentional set.

53.318 **Retinotopically defined parietal regions and their relationship to parietal areas involved in object individuation and identification**

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Based on results from visual short-term memory (VSTM) studies, Xu and Chun (2009) recently proposed a neural object file theory, arguing that visual objects are first selected based on their spatial/temporal information (object individuation), after which their features are encoded (object identification). These two processes are dissociated within intraparietal sulcus (IPS), such that inferior IPS, an area at the junction of the transverse occipital

sulcus and the bottom of IPS, is responsible for object individuation, while superior IPS is more involved in object identification. IPS has also been subdivided into at least five separate regions based on retinotopic mapping (Swisher et al, 2007; Konen and Kastner, 2008). However, as of yet, no one has been able to answer the critical question of what functional distinctions exist between these retinotopic regions. Moreover, the degree of overlap between these regions and the IPS regions described in Xu and Chun (2009) remains unclear. As retinotopic regions are prime candidates to support spatial indexing and selection mechanisms, inferior IPS likely lies within the lower IPS regions. However, as superior IPS tracks the amount of visual information encoded, regardless of location, this region may lie outside of these maps. Consistent with this view, Sheremata et al (2010) showed that VSTM activity co-localizes with retinotopic mapping in early IPS regions, but deviates from it in superior and anterior regions. Here, we performed separate inferior and superior IPS localizers, as in Xu and Chun (2009), and compared this data on an individual subject basis to retinotopically defined IPS0-4 regions. The majority of the inferior IPS region was actually found within V3A, with some overlap with IPS0. The superior IPS region, however, was localized primarily in IPS2. These results provide new insights into the functional distinctions among the different retinotopic maps seen along the dorsal visual pathway.

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53.319 Does covert attention alter perceived contrast? Evidence from gender perception.

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The current study evaluated the theory that attention boosts perceived contrast (Carrasco, Ling, & Read, 2004) by employing a novel measure of contrast: gender perception of ambiguous faces. Given that the apparent gender of a face has been shown to be related to contrast (Russell, 2009), we sought to use gender perception as a measure of whether perceived contrast indeed increases with attention. Participants performed a gender judgment task wherein the locus of attention was independently manipulated prior to stimulus presentation. On each trial, after 800 ms of fixation, an exogenous peripheral or neutral cue appeared for 50 ms, followed by a 50 ms presentation of the lower-region of two ambiguous faces. Participants reported which of the two faces appeared to be more female (Experiment 1) or more male (Experiment 2). Results showed that as the brightness contrast of a face increased, participants were less likely to report the face as female (Experiment 1) or more likely to report it as male (Experiment 2). While this contrasts with the demonstration by Russell (2009), a key difference is that we manipulated image contrast, whereas Russell specifically manipulated the contrast of the lips and eyes to the remaining face. Critically, the effect of attention did not consistently follow the effect of physical contrast on face perception, meaning that attention did not increase perceived contrast. Instead, attention increased the tendency to report a face as being more female (Experiment 1) or more male (Experiment 2). Our results support the hypothesis that attention does not boost perceived contrast, but instead causes an increase in the tendency to report stimuli in the attended region as being more salient (Schneider & Komlos, 2008).

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53.320 Perceptual load effect is determined by resource demand and data limitation

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Conventionally, perceptual load studies have looked at distractor processing via the flanker compatibility effect (FCE) by manipulating attentional resource demands to examine the locus of selective attention. Brief exposure duration has been integral to previous studies investigating perceptual load but has been generally overlooked as a form of data limitation. Norman and Bobrow (1975) have argued that task performance can be determined by both resource limitations and data limitations. Not recognizing brief exposure duration as a data limitation has led to the supposition that the extent to which distractors are processed is entirely dependent on the relevant resource limitations. To investigate the cause of the perceptual load effect, data limitations were lessened by employing response terminated displays where the target and distractors were present until response (Experiment 1), the target and task-relevant distractors were present until response (Experiment 2), or the task irrelevant distractor was present until response (Experiment 3). The results showed a significant FCE in high load,

response terminated displays which suggests distractor processing to the point of meaning. Furthermore and counter-intuitively, the data limitation induced by briefly presenting the target and task relevant distractors contributes more to the abolishment of the FCE than data limitations imposed on flankers themselves. These results support a revised version of perceptual load theory which is based on resource demands as well as accompanying data limitations.

53.321 Effect of feature and response conflicts on the spatial allocation of attention

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Previous research has suggested that attention is inhibited from returning to previously attended locations, and that this inhibition of return (IOR) lasts approximately two to three seconds. However, Tipper, Grison, and Kessler (2003) showed that this inhibition can last for much longer durations so long as the cue is encoded in a context-rich event. Using a target-target procedure, Wilson, Castel, and Pratt (2006) extended this work and proposed that IOR, at both standard (i.e. typical time range) and long durations, resulted from a conflict in memory retrieval of the previous response and the current response. However, Wilson et al. only examined situations in which the response change was from withholding a response to production of a response. The question remains, then, whether suppression of a response to the previous target is necessary or whether a change in the type of response (e.g., from a left-hand to a right-hand response) would be sufficient to produce IOR. To examine this possibility, we used standard (1500 ms) and long stimulus onset asynchronies (~10,500 ms SOA) and manipulated the congruency of both the colour of and the response required for the previous and current target. In support of the memory retrieval account, significant IOR was found at the short SOA only when there was a change in motor response, but not a change in the colour feature, suggesting that a change in motor response is sufficient to cause IOR. However, there were two unexpected results: (1) no IOR was found at the long SOA when the response changed, and (2) for both standard and long SOAs, there was significant facilitation when participants were required to make the same response to both the previous and the current target. Overall, these results support that proposal that memory for a conflicting response underlies IOR.

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53.322 Saliency changes appearance

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It has been argued that salient stimuli capture attention automatically and rapidly. Also, it has been claimed that attention changes the appearance of objects. We investigated whether the appearance of salient stimuli differs from non-salient stimuli. Observers saw a circular array of eight bars. All but one bar were vertical. The orientation singleton differed by either 6° or 45° from vertical. Observers compared the luminance contrast of the orientation singleton to a non-salient element. The luminance contrast of the non-salient element had to be increased in order to match the singleton, showing that salient objects are perceived to have a higher luminance contrast. The increase in perceived luminance contrast was larger with highly salient (45° singleton) than with mildly salient (6° singleton) stimuli. Further, we investigated whether the perceived color saturation of an orientation singleton changed. We created equiluminant red stimuli and asked observers to judge their saturation. Unexpectedly, the mildly salient singleton appeared less saturated than the non-salient element. Consistent with our hypothesis, however, the highly salient singleton appeared more saturated. Further, we investigated whether stimuli that are salient because of their motion direction look different. One of eight drifting Gabors moved opposite to the others. Observers compared the Michelson contrast of the singleton Gabor to a non-salient Gabor. The salient Gabor appeared to have a higher contrast. Our results show that judgments of contrast and saturation are influenced by saliency. There has been a debate about the stage at which changes in appearance occur. Some have claimed that the effects reflect true perceptual changes while others maintain that the effects reflect response biases. We do not think that we can ultimately rule out response biases with behavioral measures alone, but we present some evidence against response biases for this series of experiments.

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53.323 **Decreasing fidelity of peripheral visual information modulates performance on the manual line bisection task**

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The line bisection task—commonly used as a clinical measure of unilateral neglect—requires participants to place a mark on a horizontal line to indicate where they think center is. Previous research suggests that the allocation of attention mediates performance on this task. Interestingly, previous eye tracking research has shown that participants rarely explore the endpoints of lines. As a result, any conceptualization of line bisection behavior must take into account this lack of visual exploration. We endeavored to show how participants could arrive at an accurate judgment of center while minimizing ocular exploration. We hypothesized that accurate line bisection depends on the fidelity of visual information in the periphery. Lines were presented to participants either as black lines or as lines that contained either symmetrical or asymmetrical ‘noise’ (i.e., monochromatic static). Participants were asked to judge center by placing their finger on a touch screen where they believed center to be. Consistent with the literature, we found that bisections erred slightly to the left in the no noise condition (i.e., pseudoneglect) in addition to an increased leftward bias for lines presented in left space. Contrary to our expectations, symmetrical noise produced an increased leftward bias relative to the control condition. Additionally, asymmetrical noise shifted bisections towards the end of the line that contained the most noise. Finally, the degree of bias was largest in all conditions for lines presented in left space. These results indicate that the fidelity of peripheral visual information mediates bisection behavior. Furthermore, these results suggest that attention serves to remove the influence of distracting information rather than for sensory enhancement. Finally, the pattern of results for lines presented in left versus right space supports the converging line of evidence implicating right parietal cortex in governing the allocation of attention towards objects in space.

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53.324 **A new test of habituation as an account of inhibition of return in spatial attention**

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Animals reflexively orient toward unexpected events. If these events are repeated without consequence, there is a decrement in orienting called habituation. It has been proposed that one aspect of human spatial attention, inhibition of return (IOR), is best understood as an instance of habituation (Dukewich 2009; Huber, 2008). Consistent with this account, increasing the number of non-predictive cues, and increasing their rate, both lead to greater IOR (Dukewich & Boehnke, 2008). This study examines an untested premise of the habituation account of IOR, namely, that attentional orienting is necessary for habituation to occur in the first place. If habituation only occurs to attended events, it should be reduced when cues hold less information with respect to the primary task of target identification. We manipulated cue information by varying temporal predictability. In a fixed-cue condition, either 1, 3, or 5 non-predictive spatial cues were presented at one of three rates of presentation, leading to a pattern of results consistent with the known characteristics of habituation. A jittered-cue condition was identical, except that a time jitter of +/- 100ms was added to the rate of presentation, making the event sequence within a trial less predictable. Although participants in both conditions showed increased IOR as the time between the first cue and the target was increased, cue number had an influence in the fixed, but not in the jittered, condition. In addition, this difference was largest in the fastest rate of presentation, where the added jitter had the greatest effect on event predictability. These results establish the importance of initial orienting for habituation to occur in a spatial attention task. Temporal uncertainty among the cues and targets reduces orienting to individual cues, thus preventing the buildup in habituation otherwise associated with successive, predictable, cues.

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53.325 **Attention-Dependent Hemifield Asymmetries When Judging Numerosity**

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Introduction: Previous research has indicated that numerosity judgments are significantly better for stimuli distributed across the left and right hemifields than for stimuli falling entirely within either lateral hemifield (Delvenne, Castronovo, Demeyere, & Humphreys, 2009). Here, we explored numerosity-task asymmetries between the left, right, upper and lower hemifields while requiring two different attentional selection criteria; proximity grouping versus similarity grouping. Method: Twenty Denison University undergraduates viewed briefly flashed (200 msec) displays containing spatially intermingled black dots and white dots across all four quadrants, and a central letter. The task was two-fold. After reporting the central letter, participants made a same / different numerosity judgment about a cued hemifield. Half of the trial blocks required judging numerosity based on proximity (e.g., upper left quadrant versus upper right quadrant). The other blocks required judging numerosity based on color-similarity (black dots versus white dots). The independent variables were hemifield (left, right, upper, lower) and grouping (proximity versus similarity), and were completely counter-balanced within-subjects. The dependent variable was d' ; hits and false alarms were operationally defined as correct and incorrect “different” responses, respectively. Critically, retinal stimulation was identical across all (four hemifield x two grouping) eight experimental conditions. Results: The statistical interaction between hemifield and grouping was significant ($F(3,57)=4.234$, $p=0.009$, partial $\eta^2=0.182$). For proximity grouping there was a significant bilateral effect: d' was significantly greater in the lower than upper hemifield ($t(19)=4.325$, $p<.001$, partial $\eta^2=.496$), but statistically indistinguishable in the left and right hemifields ($t(19)=0.365$, $p=0.719$, $\eta^2=.007$). For similarity grouping there was a significant unilateral effect: d' was significantly greater in the left than right hemifield ($t(19)=3.021$, $p=.007$, partial $\eta^2=.324$), but statistically indistinguishable in the upper and lower hemifields ($t(19)=0.587$, $p=.564$, partial $\eta^2=.018$). Conclusion: When judging numerosity, hemifield asymmetries vary systematically with attentional selection criteria, i.e., proximity grouping versus similarity grouping.

53.326 **Conceptual Cues for Visual Attention**

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It has been suggested that processing concepts with either prototypical spatial information (e.g., hat vs. shoes) or metaphoric-spatial associations (e.g., god vs. devil) engages visual-attentional mechanisms, orienting attention toward regions of the visual field congruent with concept meaning. Interestingly, both facilitatory (Chasteen et al., 2010) and inhibitory (Estes et al., 2008) effects have been reported as consequences of these shifts of attention. Here we examine two possible causes of this discrepancy. One possibility relates to the nature of the task; tasks requiring target detection may receive facilitation from processing congruent concepts while tasks requiring target discrimination may receive inhibitory effects. A second possibility relates to the nature of the concepts that cue attention; abstract concepts (e.g., god, devil) may invoke facilitatory processes, while concrete concepts (e.g., hat, shoes) invoke inhibitory processes. In Experiment 1, a single word at fixation, either an abstract or concrete concept, preceded a peripheral target (above or below fixation) and subjects were asked to detect the targets as quickly as possible. In Experiment 2, the same procedure was used except that subjects were asked to identify the targets as quickly as possible. To ensure semantic processing of the words, subjects were asked to respond only on trials when the word belonged to a pre-specified category (e.g., divine words). Opposite patterns of results were found across the two concept types: for abstract words, responses were faster in both tasks when target location and word meaning were compatible relative to when they were incompatible. This pattern was reversed for concrete concepts, with faster responses during incompatible trials relative to compatible trials. It appears that the nature of concepts underlies the qualitatively different attentional effects previously reported.

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53.327 Eye movements during an enumerating-by-pointing task enhance spatial compressionCourtney Harman¹(charman@eden.rutgers.edu), Harry Haladjian², Deb Aks², Zenon Pylyshyn²; ¹Rutgers University, ²Rutgers Center for Cognitive Science

Observers can accurately enumerate and localize sets containing up to five randomly-placed dots when using an “enumerating-by-pointing” method (Haladjian & Pylyshyn, 2010). Analyses of localization errors suggest a form of compression, where location responses are closer to the centroid of the set of dots than their actual locations on the stimulus screen. We address the following questions in the current study: Is this compression stronger around the centroid of the dots or the point of central fixation? Is the frequency of fixations correlated with response accuracy? Is compression of pointing responses linked to eye-movements? We used an EyeLink 1000 eye-tracker to examine the role of eye-movements in our enumerating-by-pointing task. Participants were shown a display with 1-10 randomly-placed black dots (~1° diameter). This gaze-contingent display appeared immediately after participants fixated the center of the screen for one second. After a full-screen mask, participants used a mouse to place markers on a blank screen indicating the perceived locations of the dots. Analyses were performed on enumeration accuracy and localization errors (distance between dots and nearest response marker). Results show strong compression around the centroid of dots, and some compression around fixations (i.e., localization errors are smaller and less variable around the centroid). Stronger compression (on 2/3 of the cases) required at least one fixation to the centroid. More fixations, as well as dots, also strengthened centroid compression. Increased fixation frequency, however, did not improve localization or enumeration performance. Overall, these results suggest that compression is centered on the centroid of a set of stimuli, and eye-movements play a role in perceived shrinkage of the display configuration, but not judgments associated with counting.

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53.328 Visual processing speed is modulated by prior knowledge and alertnessAnders Petersen¹(anders.petersen@psy.ku.dk), Signe Vangkilde¹; ¹Department of Psychology, University of Copenhagen

Information about coming events is of great importance for attentional performance. This has been demonstrated repeatedly by a speeding up of reaction times following spatial cueing of an upcoming target (e.g., Posner et al., 1980). In contrast, a significant benefit of cueing on recognition accuracy has only rarely been demonstrated (e.g., Van der Heijden et al., 1985), even though accuracy-based approaches provide more direct measures of cueing effects not confounded by motor preparation. Cueing paradigms usually assess performance at one specific target exposure, however, we argue that varying the exposure duration of the target allows for a more detailed characterization of cueing effects. Thus, we devised a spatially cued single-letter recognition paradigm with varied exposure durations (10-140 ms). In every trial the letter was presented in one of four boxes positioned at the corners of an imaginary square. The paradigm comprised four equally likely cueing conditions: 1) valid, 2) invalid, 3) neutral, and 4) no-cue. Cueing consisted in initiating one of the boxes 100 ms before the letter and the remaining boxes. In the neutral condition all four boxes were initiated 100 ms before the letter. Eye tracking was used to ensure that participants fixated centrally, and trials with eye movements were discarded and re-run online so all participants completed the same total number of trials. The results provide evidence to suggest that the observed effects of cueing involve at least two components influencing visual processing speed, i.e., a non-spatial alerting component induced by the appearance of the cue evident in Conditions 1-3, and a spatially specific expectation component evident in the valid and invalid conditions. We show how the contributions of these components can be described and modeled mathematically using the Theory of Visual Attention (Bundesen, 1990).

53.329 How recent visual experience modulates what we look at firstYuan-Chi Tseng^{1,2}(yctsens@ski.org), Joshua Glaser³, Eamon Caddigan^{2,4}, Alejandro Lleras^{2,4}; ¹Smith Kettlewell Eye Research Institute, ²Beckman Institute, University of Illinois at Urbana-Champaign, ³Mathematics & Physics, University of Illinois at Urbana-Champaign, ⁴Psychology, University of Illinois at Urbana-Champaign

When searching for an oddball target, the stimulus in the preceding trial influences performance on the current trial. Responding to a target among two distractors on the current trial is faster when the preceding trial had the same target and distractors colors than when the target and distractor colors were switched (priming of Pop-out, PoP). Finding the oddball is also faster when the preceding trial has no oddball and all elements share the same color with the current distractors, compared to when they share that of the target (distractor previewing effect, DPE). These inter-trial effects are understood in terms of two possible processes: (I) a bottom-up modulation of stimulus visibility, or (II) a top-down modulation on the prior expectation of the oddball feature. Here, we combined these two tasks in a saccade choice experiment (1600 trials) and fit our data with a diffusion model. The drift rate and the thresholds of the diffusion process reflected stimulus visibility and prior target expectation, respectively. All observers showed robust PoP and DPE effects. The best fitting parameters of the diffusion model were compared to unveil the possible modulations underlying PoP and DPE in each participant. The shorter latencies in PoP when the oddball color is repeated may be explained by an increase in target drift rate as well as a smaller decrease in target decision threshold. The model also strongly suggests that the distractor preview condition is associated with a smaller increase in distractor drift rate and a more robust and substantial decrease in threshold, accounting for changes to saccade latencies and accuracy in the DPE. The data and modeling show how a modulation of the same nature (albeit in different directions) underlies these inter-trial effects: repeating a target feature increases its visibility whereas feature status (target or distractor) modulates attentional decision thresholds.

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Perceptual organization: Segmentation and grouping

Tuesday, May 10, 8:15 am - 12:15 pm

Orchid Ballroom, Poster Boards 401 - 419

53.401 Third Order Edge Statistics Reveal Curvature DependencySteven Zucker^{1,2}(steven.zucker@yale.edu), Matthew Lawlor², Daniel Holtmann-Rice¹; ¹Computer Science, Yale University, ²Applied Mathematics, Yale University

While neural circuits in vivo connect many thousands of different cells, statistical and measurement complexity limit functional data to pairwise interactions. This is especially important in visual cortex, superficial V1, where pairwise edge co-occurrences have supported an association field model for long-range horizontal connections. However, how well do such low-order models capture the (higher-order) neural structure? Computationally it is known that such second-order (pairwise) models can account for the mean of the connection distribution, but fail to predict the variance in connections across cells.

We developed a method for estimating a third-order statistic for edge element interactions by conditioning the second-order interaction on a third element. Diffusion maps are used to reveal a global organization of the data, and embedded points that cluster together model the connections. A significant asymmetry emerges for experiments with natural images and Glass patterns: (i) Excitatory (third-order) connections depend on curvature. This dependence models co-circularity and predicts both the mean and the variance in population statistics of excitatory connections. (ii) Inhibitory connections are more uniformly distributed across orientation and position. Consistent with axonal projections of inhibitory interneurons in V1, there is no dependency on curvature.

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53.402 Context integration across hemispheres in neurons of the visual cortex

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Most neurons in visual cortex respond to contrast borders and are orientation selective, and some are also selective for which side of a border is figure and which side is ground ('border ownership coding'). These neurons are influenced by the image context far beyond the classical receptive field (CRF), and as early as 25ms after the onset of activity in the cortex. Using fragmented figures, Zhang and von der Heydt (J Neuroscience 2010) were able to quantify the contribution of each part of the figure contour. They found that contours on the preferred border ownership side facilitated, while contours on the non-preferred side suppressed responses, with about 80% of the locations contributing on average. Here, we studied context integration across the cerebral hemispheres. Neurons were recorded from monkey V2 under behaviorally induced fixation. The basic test figure was a contour-defined square akin to the Cornsweet illusion that could be decomposed into eight fragments. One edge was centered in the CRF, and the fragments outside the CRF were presented in varied composition. Some of the fragments were in the same hemifield as the CRF, and thus represented in the same hemisphere with the recorded neuron, whereas others were in the opposite hemifield and could influence the neuron only through interhemispheric commissures. Using linear regression, we computed the influences of individual fragments as a function of time after stimulus onset. We found no significant difference in time course between the context influences from the two hemifields, whether facilitatory or suppressive. Thus, border ownership selective neurons integrate information evenly across hemispheres. The interhemispheric transfer does not seem to cause major delays.

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53.403 Influence of real and illusory contours on center-surround masking

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Numerous experimenters have posited a strong link between subjective appearance and performance on different low-level visual tasks. It has been suggested that the subjective appearance of stimulus components in center-surround masking experiments act to segregate the components. The current experiment was designed to systematically measure the effect of real (mean luminance difference between center and surround) or illusory (contrast, phase, spatial frequency, or orientation differences between center and surround) contours on the psychometric functions of center-surround masking of suprathreshold orientation discriminations. Correlated changes in the psychometric functions' shape and position would suggest that the mechanism responsible for reducing or removing masking effects in center-surround stimuli responds to contours, independent of how they were created (higher-level processing). Uncorrelated changes in shape and position would suggest a mechanism that treats information from first- and second-order channels differently. It is also possible that illusory contours created by different dimensions may produce different results. This would be even more support for differential processing of low-level spatial information. The results indicate significant shifts in the shape and position of the psychometric functions for all dimensions, from low levels of texture segregation to high levels of texture segregation. At their highest level of texture segregation there is no significant difference between the shape and position of the curves. This suggests that texture segregation plays a large role in the reduction of masking in center-surround stimuli; independent of how the components are segregated.

53.404 A systematic look at the relationship between texture segregation and center-surround masking.

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Previous research has shown that surround masking of a sinusoidal grating can decrease performance on a discrimination task. It has also been shown that the similarity of the mask to the target influences the degree to which performance is affected by the mask. One hypothesis states that perceptual segregation caused by differences in center and surround allows for more independent processing of the two components, thus reducing masking. In order to test this hypothesis, observers performed a standard texture seg-

regation task (determining whether a texture rectangle is vertical or horizontal), using relative differences in phase, orientation, spatial frequency, contrast, and mean luminance between the rectangle and its surround. The results of this task provided psychometric functions of texture segregation for each dimension. These data were then used to create several levels of equally-salient illusory contours (across different dimensions) between a target center and a masking surround. If texture segregation is indeed the key for reducing center-surround masking, orientation discrimination performance should be equivalent for similar levels of contour salience, no matter what dimension is being varied. We found strong positive relationships between texture segregation performance and orientation discrimination performance. The relationships were virtually identical across the different dimensions.

53.405 Empirical data on the configural architecture of human scene perception and linguistic labels using natural images and ambiguous figures

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Purpose: Both local and configural processes play a role in the figure-ground organization of scenes. Local factors include bottom-up edge segmentation enabling small regions to be fused into figural regions. The Berkeley Segmentation Dataset (Martin, Fowlkes, Tal, & Malik (2001)) provides a corpus of images whose contours were hand segmented by humans, making it ideal for studying local processes. Configural factors include top-down processes such as grouping and meaningfulness. Barghout (2009) created a complementary dataset designed to capture the configural information required for studying top-down processes. In this study we collected more data for the images in this corpus to enable rigorous statistical analysis. The data-collection paradigm assumes that asking someone to mark the "center of the subject of the photograph" serves as a proxy of the figural status of the region centered at the point marked. Since the method does not distinguish between a foreground, a single object or an object within an object, we coined the term 'spatial taxon' to refer to the object or object group centered at the position indicated. This operational definition is analogous to - but also much broader than - the term 'figure' as defined in the literature. Methods: Participants were asked to "mark the center of the subject of the photograph" and label it. K-means clustering was used to determine spatial taxons, as operationally defined above. Rank-frequency distributions for spatial taxons and corresponding word labels were fit via linear regression.

Results: Results suggest natural-scene-perception architecture comprised of nested hierarchies whose rank-frequency, and corresponding word rank-frequency are described by inverse power laws. Unlike the results for natural scenes, spatial taxon rank-frequency distribution for two of the three ambiguous figures were uniform and word labels corresponded to their percepts; supporting the assumptions underlying the methodology.

Acknowledgement: Eyegorithm

53.406 ERP signatures of Gestalt cues predict perceptual segmentation.

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Gestalt cues are thought to organize visual input into meaningful perceptual units during pre-attentive stages of human visual information processing. As these units then serve as input for further perceptual and cognitive processing, characterizing the influence of Gestalt cues on their formation can lead to a better understanding of how the visual system initially organizes sensory input, as well as to the development of techniques to better present observers with critical visual information. Towards these ends, we used ERPs to a segmentation task in conjunction with psychophysical measures to map the time courses of several Gestalt cues. Observers determined whether patterns of 100 Gabor patches formed rows or columns. Patterns were formed by parametrically varying the tilt, spatial frequency, contrast, length, separation, and backgrounds of the patches. Overall, Gestalt versus Uniform stimuli showed faster correct response times, modulated P3 amplitudes, and attenuated P1 amplitudes. Relative to Uniform stimuli, stimuli correctly grouped by Proximity and Connectedness generally showed longer correct response times, later and smaller P3s, sooner and smaller P1s, and smaller N2s than stimuli grouped by Similarity of Spatial Frequency or Contrast. In contrast, stimuli grouped by Common Region and Similarity of Tilt generally showed shorter correct response times, sooner and larger P3s,

later and larger P1s, and larger N2s. We next use a machine-learning algorithm to decode the characteristic ERP signatures of each Gestalt heuristic. In turn, we use these signatures to predict how and when an observer will parse a novel visual stimulus based on cortical activity specific to its Gestalt context, as well as when, and to what extent several visual illusions, such as the Ponzo, Müller-Lyer, Rod-and-Frame, and Simultaneous Tilt Illusions (reflecting perceived depth, size, and orientation) are affected by each type of Gestalt cue.

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53.407 A Measure of Localization of Brain Activity for the Motion Aperture Problem using Electroencephalograms

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Problem. Through a limited-sized aperture bars appear to move in a direction normal to their orientation. The motion aperture problem is an important rubric for analyzing early stages of visual processing, particularly with respect to the perceptual completion of motion sampled across two or more apertures (M.Okada, S.Nishina and M.Kawato, Neuro Report, 14, 14, 1767-1771, 2003).

Experiment. A circular aperture is displayed in the center of the visual field, and, in a baseline condition, a bar initially appears to move from the lower-left to the top-right (its normal motion direction). While the baseline bar is moving, two additional circular apertures appear, and within each aperture a "flanker bar" appears to move in an up or down (control) direction. For these flanker bars the line ends are visible in the two apertures and thus can disambiguate the motion of the base bar. For an upwards movement of the flanker line the subjects perceive the flanker bar connected with the base bar and all three parts move upward. We investigate the motion perception of the moving bars by changing line speed, radii of the apertures, and line length while recording and then analyzing spatio-temporal brain activities by electroencephalograms (EEGs). Latencies in the brain are estimated using equivalent current dipole source (ECD) localization for two subjects.

Result. Soon after the flankers appear, ECDs are localized along the ventral pathway, which are assumed to be generated by the recognition of the aperture's form. After the bars move, ECDs are localized along the dorsal pathway, presumably generated by the motion of the bars. In addition, for the perception of veridical (grouped) motion and not normal motion, ECDs were localized to the middle frontal gyrus and the inferior frontal gyrus.

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53.408 Region-based texture segregation and orientation-similarity grouping

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Texture segregation and perceptual grouping go hand in hand but they have mostly been studied in separation, each using their own stimuli and tasks, in order to test specific models. For instance, models of texture segregation can be classified as region-based and edge-based, while in perceptual grouping two traditions of models are related to two stimulus types, with elements in random positions (e.g., in snake detection displays) or organized in a grid (e.g., dot lattices). The goal of this study was to provide a more integrated approach. We conducted two psychophysical experiments in which we presented stimuli consisting of oriented Gabors. Perceptual grouping of elements sharing similar orientations may lead to segregation from an ungrouped region with random orientations, or the two regions may be segregated based on local orientation differences at the edge between the regions. We manipulated (1) the degree of orientation similarity in one region by adding orientation jitter to the average orientation (0°-80° in 10° steps), (2) the positions of the Gabors, which were either quasi-random or in a regular grid, and (3) the edge between the two regions, which was either straight or curved. In Experiment 1 a two-interval forced-choice procedure was used with one interval containing only Gabors with random orientations and the other with one region consisting of Gabors in non-random orientations. This experiment required detection of the pattern with a non-random region. Experiment 2 required shape discrimination of the edge (straight or curved) in a yes/no task. We found (1) a gradual decline in performance with increasing orientation jitter in all

conditions, (2) lower thresholds for detection of the region than discrimination of the edge, and (3) comparable performance levels for regular and quasi-random Gabor positions. These results are congruent with region-based texture segregation and perceptual grouping.

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53.409 Emergent Features in two-line configurations prevent selective attention to individual lines as measured by Garner Interference.

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When and how do stimuli configure to produce a Gestalt? We propose that grouping may be equated with the creation of Emergent Features (EFs). Support has been previously shown for eight EFs in the context of Configural Superiority (CSE) and Inferiority (CIE) effects using an Odd-Quadrant discrimination task. The present study further tests EFs in a task of selective attention. Subjects rapidly classified stimuli composed of two elements, each of which was a straight line segment presented in one of 4 orientations: vertical, horizontal, positive diagonal, and negative diagonal. Stimuli differed on the orientation of one or both of the elements. Following Pomerantz & Garner (1973), we reasoned that when elements are perceptually organized so as to form a Gestalt, the ability to selectively attend to the orientation of any one element is impaired. Thus, if grouping, and the EFs it creates, are present, subjects should have difficulty attending to one element while ignoring variation in the other; i.e., they should show Garner Interference (GI). Our results confirmed that two-line configurations that yield CSEs also show GI, whereas configurations that don't yield CSE do not produce GI. Additionally, performance during a divided attention task, where subjects are required to pay attention to both elements simultaneously, was impaired for line pairs that did not configure but not for those that did, providing further converging evidence that grouping defines the units of selective attention.

53.410 Feature selection as a mechanism for color grouping

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The visual system forms groups out of objects that share similar features, such as color, shape, or orientation. One proposed mechanism for this similarity grouping is selection of a given feature, which should increase activation in visual field locations that contain that feature (e.g. red or vertical). Because these locations are selected together, they appear to belong together (e.g., Huang & Pashler, 2007). This mechanism makes a unique and surprising prediction - because groups are defined by selected regions, only one group can exist at a time. When we feel that we are grouping two independent sets simultaneously (e.g. two red objects and two green objects), this must be an illusion caused by rapid switching between features. We tested this idea with a visual search tasks for groups among other groups - if only one group can be created at a time, these searches should be extremely inefficient. As a control to ensure that inefficient search was due to grouping processes per se, we also asked participants to perform similar tasks with connected groups, which are known to be constructed in parallel. In one experiment, participants were extremely slow to locate an unmatched pair of colored squares (e.g., a red and blue square) among matched pairs (e.g., two green squares) (77ms/pair). In a control condition, the objects within each pair were moved closer together so that they touched and created a color contrast edge. Search was now highly efficient (16ms/pair). In a second experiment, participants were asked to search for a vertical group of dots among horizontal groups. Search was again inefficient (27ms/group) but was significantly faster when groups were connected by lines (15ms/group). Both of these results are consistent with the possibility that our feeling of grouping objects with similar features may be due to selection of those features.

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53.411 Collinearity and Containment Grouping have Different Effects on Object Substitution Masking

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Object substitution masking occurs when attention is distributed over a large region, and a sparse, non-overlapping, and temporally trailing mask impairs the perception of a briefly presented object (Enns & Di Lollo 1997).

Previous work has shown that masking is stronger if mask and target are grouped by color or motion. This led to a hypothesis that when the mask and target are within the same "object file", the trailing mask "overwrites" the file so only the mask is easily perceived (Lleras & Moore 2003, Moore & Lleras 2005). However, it is unclear whether this holds for all types of grouping. We investigated whether good continuation and containment grouping between target and mask affects masking strength. We presented subjects ($n=12$) with a ring of 8 items for 30ms, where the target was cued by a four-dot mask, with simultaneous or 320ms delayed offset, in two experiments. In the collinearity experiment, the mask was either square or rotated to form a diamond. Subjects reported the orientation of the target: a pair of horizontal or vertical lines which were collinear with the square mask, but not the diamond mask. In the containment experiment, the four-dot mask was either inside or outside the target: a spiky or wavy circle. Collinearity relieved masking, with a masking effect (% correct simultaneous - % correct delayed offset) of 8% (91%-83%) for the collinear mask, and 17% (91%-74%) for the non-collinear mask ($p=.0002$). Additionally, masking was stronger ($p=.0419$) when the mask was inside, 18% (85%-67%), compared to outside, 12% (72%-60%). Grouping was stronger when target and mask were collinear, and when the mask was inside a circular target. However, these strong grouping conditions respectively produced weaker and stronger masking. This suggests that the type and strength of grouping between target and mask has a complex relationship with mask effectiveness in object substitution masking.

53.412 The Perception of Four-Dot Configurations

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For centuries we have looked at the night sky and made shapes out of the randomly placed stars. How do we do that? What rules govern the establishment of patterns in random dots? Clearly, 2 dots always can be seen as a line segment; and 3 dots can be seen as either a line or a triangle. What about 4 dots? In a previous experiment (Pomerantz, Portillo, Hammarsten, Keshvari & Jewell, 2007) we systematically sampled all possible 4-dot arrangements, examining 328 displays in all. We presented these displays to participants in a free-classification task, and a cluster analysis of their responses produced a hierarchy of clusters in which the first bifurcation occurred between patterns having 3 (or all 4) dots falling in a straight line versus those that did not. In a second experiment we had participants identify the prototype pattern for each card group formed in the first experiment. While in some dot groups (i.e. those containing a pattern of dots in a straight line, or in a symmetric arrangement) the prototype emerged quickly and there was substantial agreement across subjects, in other groups that lacked these features, the prototype was harder to identify. In a third experiment we presented the group's prototypes to new subjects for a connect-the-dot task to verify our interpretations about the features (symmetry, linearity, parallelism, etc) that guided the initial grouping and the selection of the prototypes in each group. This third experiment indicated that, as suspected, most participants seem to use Gestalt principles to organize random dots. However, clear exceptions were also present. Overall, it appears that the visual system is geared to organize random dot displays applying a few but salient features such as linearity, symmetry and parallelism.

53.413 After-effect of perceived regularity

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Aim: Regularity is a fundamental characteristic of the visual environment. Here we consider whether regularity is an adaptable feature, specifically whether one can obtain an after-effect (AE) in perceived regularity. Method: Stimuli consisted of a 7 by 7 arrangement of dark Gaussian blobs arranged on a baseline grid. The position of each blob was randomly jittered from its baseline position by an amount that determined the degree of pattern irregularity. Observers adapted for 60 sec to a pair of patterns above and below fixation with a different amount of regularity, then adjusted the relative regularity of two test patterns to obtain the PSE. The size of the AE was given by the difference in regularity at the PSE. Results: PSEs were significantly different from zero, indicating that regularity is an adaptable feature. Additional experiments indicated that the regularity AE was not due to a) luminance spatial frequency adaptation, b) local positional adaptation or c) local orientation adaptation. Experiments using single adaptors revealed

that the AE is unidirectional, specifically that adaptation only causes test patterns to appear less regular. Conclusion: Pattern regularity is an adaptable feature in vision, but the functional significance of regularity adaptation is not yet clear.

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53.414 The Rapid Perception of Correlation in Scatterplots

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It has been shown (Rensink & Baldrige, 2010) that the perception of Pearson correlation in scatterplots can be described by two simple laws: the just noticeable difference (jnd) follows a Weber-like law, and the subjective estimate a Fechner-like law. This suggests that correlation is (or is associated with) a perceptually simple property, even though it is conveyed by a relatively complex medium.

To investigate further, the timecourse of this process was examined. Scatterplots of extent 5.0 deg were used, each containing 100 randomly-distributed points. Means were set to 0.5 of this range, and standard deviations to 0.2. An initial scatterplot was presented for 100, 400, or 1600 ms, followed by a mask of 200 ms. A second scatterplot was then presented, and remained on until the observer responded. The observer was asked to select which scatterplot was more highly correlated. Jnds were measured for base correlations of 0.3, 0.6, and 0.9. 20 observers were tested.

Results show that jnd remained Weber-like for all timescales examined. Performance for the 400 ms and 1600 ms conditions were virtually identical. Performance for the 100 ms condition was much the same as for the other two, with only a slight decrement found, indicating that the process was largely complete by that time. This pattern held for both gaussian and uniform distributions, with nearly identical performance found for both. These results suggest that the rapid estimation of statistical properties (either directly or indirectly) can occur not only for first-order quantities (Ariely, 2001) but for second-order quantities as well.

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53.415 Spatial organization and configural processing strategies: From perception to memory

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Research suggests that people have a strong tendency to organize spatial information by forming configurations rather than maintaining individual locations. Here, we considered how powerful this type of organization might be when participants completed a simple spatial reconstruction task. In a series of experiments, participants reconstructed spatial arrays that were either monochromatic or multicolored in order to promote either perceptual grouping or individuation, respectively. To investigate the role of familiar shape, we manipulated whether the displays consisted of meaningful shapes (e.g., fish) or random configurations. Finally, we asked people to reconstruct the displays either perceptually or after a short memory delay. We measured the accuracy of the reconstructions to assess whether having cues that facilitate a configural organizational strategy would improve the quality of the reconstruction. First, consistent with previous results, we observed a benefit for monochromatic displays relative to multicolored displays. Second, having a meaningful structure yielded more accurate reconstructions beyond simply seeing the shape maintained, suggesting that individual locations were more accurately preserved when they were in the context of a familiar shape. In addition, the interplay of these two factors suggested that the use of a meaningful configuration enhanced the difference between the monochromatic and multicolored displays. Finally, when we compared reconstruction from perception versus memory, we found similar results. However, participants made identity errors (i.e., swapped colors) from memory. This was true for both meaningful and random configurations, suggesting that participants were attempting to use shape information in both conditions and that people were (potentially) losing the binding of identity to location. Taken together, these results suggest that configural processing may dominate the organization of spatial representations--conditions that promote this organization facilitate localization.

53.416 Perceptual grouping weakens local feature representationDongjun He¹(hedongjuns@pku.edu.cn), Fang Fang¹; ¹Department of Psychology, Peking University

Previous studies showed that shape perception could reduce activity in human primary visual cortex (Murray et al., 2002; Fang et al, 2008). But the functional role of the reduction is still unclear. Here we performed psychophysical adaptation experiments to address this issue. Subjects adapted to a thin diamond with its four corners hidden by three horizontal occluders. The diamond translated with a circular trajectory. Its speed was 3.38 °/s and its direction (clockwise or counter-clockwise) reversed every 5 s. Due to the existence of the occluders, only four bars (part of the sides of the diamond) were visible, but subjects were able to group them into a translating diamond (the diamond stimulus). The width of the bars was 1.80 ° and their orientations were 25 ° tilted (left or right). Their luminance was modulated spatially by a sine function (2 cycles/°) and their Michelson contrast was 1. A second adapting stimulus (the non-diamond stimulus) was generated by slightly changing the positions of the occluders in the diamond stimulus, which then could not be perceived as a moving diamond. Both the diamond stimulus and the non-diamond stimulus were presented in the left visual field. We measured two local aftereffects induced by adaptation to one of the four bars – tilt aftereffect (TAE) and threshold elevation aftereffect (TEAE). We also measured high-level shape aftereffect (SAE) by presenting normal or close-to-normal diamonds (their aspect ratios were around 1) in the right visual field. Compared with adaptation to the non-diamond stimulus, adaptation to the diamond stimulus induced a stronger SAE, but weaker TAE and TEAE. These results suggest that perceptual grouping enhances shape representation in high-level shape selective areas (e.g. LOC), but meanwhile, weakens local feature representation in early visual areas (e.g. V1), which provides psychophysical evidence for the predictive coding theory (Mumford, 1992).

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53.418 Closure versus symmetry: rapid competition of two grouping principles in a primed flanker paradigmFilipp Schmidt¹(filipp.schmidt@sowi.uni-kl.de), Thomas Schmidt¹; ¹Department of Psychology I, University of Kaiserslautern

Grouping processes are exceedingly important to organize our environment into coherent units. However, perceptual grouping is no unitary process but a mixture of several coexisting mechanisms which seem to vary fundamentally in their time course and attentional demands. We performed two experiments to compare the time courses of two different perceptual grouping principles (grouping by closure and by symmetry) in response priming effects. Primes and targets were arranged in a flanker paradigm, such that two primes were presented side by side at the center of the screen. Targets appeared after a systematically varied stimulus-onset asynchrony (SOA) and flanked the primes. Primes and targets were stimuli from the same pool (Exp. 1: systematically produced shapes, Exp. 2: random shapes), where each single stimuli could be classified with respect to the both dimensions of closure-openness and symmetry-asymmetry. Participants should either respond to the openness or symmetry of the targets, whereat primes could trigger the same or conflicting responses. Response times and error rates showed differences in their magnitude and priming effects depending on SOA and response-relevant grouping principle. In general, grouping by closure was faster and more efficient than that by symmetry. We conclude that both principles are in fact considerably different regarding their time course and influences on the visuomotor system, especially with regards to early visual processing.

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53.419 Long-range, pattern-dependent contextual effects in early visual cortexSung Jun Joo¹(sjjoo@uw.edu), Geoffrey Boynton¹, Scott Murray¹; ¹Department of Psychology, University of Washington

A stimulus that deviates from a pattern can be readily detected, indicating an enhanced representation of this stimulus in the visual system. We demonstrate that neural activity in early visual cortex may mediate global, pattern-dependent saliency. We manipulated the saliency of an oriented target Gabor using both adjacent and remote flankers. For example, a vertically (V) oriented target can be considered a part of a pattern when surrounded by flankers of the same orientation (same condition: V-V-V or V-V-V-V-

V). The identical target becomes salient when it deviates from the orientation of adjacent horizontal (H) flankers (orthogonal condition: H-V-H or H-H-V-H-H). However, the saliency of the target can be reduced by remote flankers by forming a global, repeating pattern (pattern condition: V-H-V-H-V). Critically, in the pattern condition, the local configuration (e.g., H-V-H) is the same as the orthogonal condition thus any changes in response to the target result from long-range processes.

We assessed the response to the target as a function of pattern-dependent saliency using: (1) contrast adaptation, (2) reaction time (RT), and (3) fMRI. The target produced greater adaptation in the orthogonal condition than in the same condition, suggesting higher neural activity for a salient target. Critically, the amount of adaptation decreased in the pattern condition compared to the orthogonal condition, even though the local configuration remained equivalent. We found that RTs were faster for detecting the target in the orthogonal relative to the same and pattern conditions. An fMRI experiment also demonstrated higher responses to the target in V1-V3 in the orthogonal compared to the same and pattern conditions. Overall, these converging findings suggest that global pattern information is encoded in early visual cortex and that neural responses are modulated by both adjacent and remote stimuli.

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Attention: Shifting

Tuesday, May 10, 8:15 am - 12:15 pm

Orchid Ballroom, Poster Boards 420 - 428

53.420 Reducing task switch cost with action video gamesKatherine Medford¹(kmedford@bcs.rochester.edu), Michael Sugarman¹, C. Shawn Green², E. Klobusicky¹, Daphne Bavelier¹; ¹Department of Brain and Cognitive Sciences, University of Rochester, ²Department of Psychology, Center for Cognitive Sciences, University of Minnesota

The ability to quickly shift between tasks is a main determinant of executive control. Here we ask whether such an ability can be modified by action video game play using an adaptation of the Monsell, Sumner, and Waters (2003) paradigm in which subjects switch tasks predictably every four trials. In our first experiment, subjects switched between reporting the color or the shape of an object by means of either a manual or a vocal response (in separate blocks). Avid action video game players (VGPs) displayed a smaller cost in task switch than non-video game players (NVGPs), indicating an enhanced ability to efficiently shift between mental sets in habitual players of fast-paced games. Importantly, this effect was not restricted to manual responses, which are arguably well trained in VGPs, but also generalized to vocal responses. Experiment 2 confirmed that this effect was not specific to perceptual tasks but was also present in cognitive tasks by presenting digits and asking subjects to switch between an odd-even and a magnitude judgment task. Experiment 3 established the causal effect of action game play in switch cost reduction through 50 hours of training. Finally, experiment 4 investigates the effect of predictability with an unpredictable task switch paradigm, assessing whether the VGP advantage holds when an upcoming switch cannot be anticipated. Together these results indicate that the very act of playing action video games facilitates a key aspect of cognitive control, task switching.

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53.421 The Effect of Visual Scanning in Line BisectionKatsumi Minakata¹(kminakata@gmail.com), Yamaya Sosa¹, Mark E. McCourt¹; ¹Center for Visual and Cognitive Neuroscience, Department of Psychology, North Dakota State University

Pseudoneglect refers to a systematic leftward bias in the perceived midpoint of horizontal lines, and reflects the specialization of the right hemisphere for the deployment of visuospatial attention. Line scanning direction modulates this tonic bias such that leftward error increases with rightward scanning and decreases with leftward scanning. The origin of this scanning effect is unknown. Using eye-tracking and tachistoscopic line bisection task (Mccourt & Olafson, 1997), the type (saccadic vs. smooth pursuit) and direction (leftward vs. rightward) of attentional scanning, executed with or without eye movements (overt vs. covert), were manipulated. Observers overtly or covertly attended a smoothly (11.5o/s) or suddenly moving dot in a leftward or rightward direction toward the center of the display.

Contingent upon a centered gaze location, pre-transected lines were then presented for 150 ms. Subjects made forced-choice judgments of transector location relative to line midpoint. No-scanning and manual line bisection (transector moved rightward or leftward via mouse from one line endpoint until judged to be centered) conditions served as controls. There was a main effect of scanning direction where, contrary to previous reports (Chokron & Imbert, 1993), leftward scanning resulted in leftward error, and vice versa. This was true for the manual scanning condition as well. Smooth pursuit was more potent than saccadic scanning, and overt scanning was more potent than covert scanning. The strongest effects occurred with leftward overt smooth pursuit scanning. If bisection error is due to differential attentional magnification of line halves, then our results imply that visuospatial attention is deployed asymmetrically ahead of a scanned target.

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53.422 Visual relationship judgments

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We often need to encode relative visual differences between objects. Which of the last two pieces of pie is bigger? Which tomato is redder? Which football team brought more fans? Is Mary taller than Jill? Surprisingly, there is almost no literature exploring this fundamental visual ability. The mechanism that allows us to encode relative differences must solve a difficult problem - the compared features must be bound to the correct objects. Although we feel that we judge relative differences between objects by selecting both simultaneously, this strategy would likely result in binding problems. Instead, we argue that across a range of relative judgment abilities in vision, we select a first object, load its relevant values into memory, select a second object, and then compare the currently selected values with the values in memory. This account makes a strong prediction: that even when making the most simple relation judgment about two objects, selection must shift from one object to another. We tested this idea by seeking evidence of a likely shifting pattern: moving from left to right, as in reading order. When students judged the relative height of two rectangles, they were 52 ms faster when the objects appeared over time in left to right order (200ms SOA), compared to the when they appeared right to left, suggesting that the left to right animation was congruent with their natural inspection order. Critically, this advantage disappeared in a control experiment where the relation aspect of the task was removed (a same-different judgment). A second experiment replicates these results, and the control results, using circle diameter instead of bar height. These results suggest that the binding demands of relation judgments require that objects be sequentially selected.

53.423 Spatial relationship judgment requires selection of each object in turn, even when object identification does not

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We often need to process the spatial relationships between objects; e.g., when noticing that your mouse is to the right of your keyboard. One challenge of spatial relationship judgments is properly binding different identities with their respective positions, even when those identities can be extracted in parallel. One solution to this problem is to select one object at a time - if so, then even in the simplest spatial relationship judgments where we feel that we select two objects at once (keyboard and mouse), we must actually select single objects in a sequence over time (keyboard -> mouse). To demonstrate this effect, we primed participants with a Navon letter task to select either single (local attentional scope) or multiple (global attentional scope) objects, immediately before performing either a spatial relationship judgment between two colors (which should require proper binding) or a same-different identity judgment between the two colors (where binding should not be important). There was an interaction such that spatial relationships were judged faster under single object selection primes, and same-different identity was judged faster under multiple-object selection primes. These results provide evidence for a counter-intuitive possibility - that even when object identities are available, knowing where they are relative to each other requires that we select them sequentially over time.

53.424 Tailgate masking: the obliterating effect of the unattended pre-mask

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In standard masking paradigms it is not possible to attend to a target without also attending to the masks that precede and/or follow it. However, in this experiment, we used an apparent motion paradigm where observers could attentively track a central target location without attending to the masks, allowing us to examine if the strength of masking depends on the amount of attention falling on the masks.

Three adjacent stimuli -- a mask, a target, and a mask -- stepped along a path circling fixation. The displacement on each step matched the spacing between the stimuli so that each location received a temporal sequence of mask-target-mask. At high target contrasts, the target was clearly visible at the location between the masks. At lower contrasts however, the target vanished, leaving a blank space between the two masks. This result was robust over a wide range of timings and spacings.

We then changed the spacing of either the preceding or the following mask so that one of the masks no longer fell on the target location on each step. When only the mask preceding the target was aligned with the target, the masking was slightly reduced compared to when both pre- and post-masks were aligned on the target. The post-mask alone had little effect on the target visibility. This indicates that masking can occur even when no attention is allocated to the mask but the effectiveness of unattended masks arises principally from the pre-mask (forward masking).

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53.425 Perceived biological agency in a Slithering Snake animation

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A central task for human vision is to detect the presence of animate agents in the local environment. In studies of perceived animacy, single geometric shapes move in patterns that elicit percepts of animacy and goal-directedness. In studies of biological motion, complex 'point-light' body structures engage in highly specialized kinematics that elicit percepts of biological agency. Here we explore a possible midpoint between these phenomena with a novel display -- the Slithering Snake animation -- consisting of a line of small discs, each of which always maintains a short distance from its neighbors. The discs move according to an extremely simple algorithm: the head disc moves randomly, and each subsequent disc moves toward the disc in front of it. This display triggers a rich, compelling percept of snake-like biological agency. We explored the influence of the Slithering Snake on attention and perspective-taking, based on the treatment of the randomly-moving disc as the agent's 'head'. First, in a probe detection task, we found that attention is automatically attracted to the head (compared with the center, or 'tail'). This effect was due to perceived agency, and not to lower-level motion differences or predictability, since the effect (a) reversed when the animations played in reverse order; and (b) largely decreased or even disappeared when the endpoints moved identically, but the snake's middle was invisible or was a rigid line. Second, participants had to quickly identify whether a probe was presented to the left or right of the discs. Responses were slowed considerably when the snake's perspective conflicted with their own (as in a probe to the left of the discs, but to the right from the snake's perspective). These effects show how the perception of biological agency can be generated by surprisingly simple cues, and how such percepts automatically influence other perceptual and cognitive processes.

53.426 Realization of an Inverse Yarbus Process via Hidden Markov Models for Visual-Task Inference

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It has been known for a long time that visual task greatly influences eye movement patterns. Perhaps the best demonstration of this is the celebrated study of Yarbus showing that different eye movement scanpaths emerge depending on the visual. Forward Yarbus process, the effect of visual task on eye movement pattern, has been investigated for various tasks. In this work, we have developed an inverse Yarbus process whereby we can infer

the visual task by observing the measurements of a viewer's eye movements while executing the visual task. To do so, first we need to track the allocation of attention, for different tasks entail attending various locations in an image and therefore tracking attention will lead us to task inference. Eye position does not tell the whole story when it comes to tracking attention. While it is well known that there is a strong link between eye movements and attention, the attentional focus is nevertheless frequently well away from the current eye position. Eye tracking methods may be appropriate when the subject is carrying out a task that requires foveation. However, these methods are of little use (and even counter-productive) when the subject is engaged in tasks requiring peripheral vigilance. The model we have developed for attention tracking uses Hidden Markov Models (HMMs), where covert (and overt) attention is represented by the hidden states of task-dependent HMMs. Fixation locations, thus, correspond to the observations of an HMM and were used in training (by using Baum-Welch algorithm) task-dependent models whereby we could evaluate the likelihood of observing an eye trajectory given a task (forward algorithm). Having this likelihood term, we were able to use the Bayesian inference and recognize the ongoing task by viewing the eye movements of subjects while performing a number of simple visual tasks.

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53.427 **Continuously moving RSVP task revealed neuronal activities related to position of spatial attention: an fNIRS study**

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Variation of position of visuospatial attention causes modulation of neural activities. This phenomenon has been clear in early visual cortex revealed by fMRI studies. Here, we demonstrate that this effect could occur even in lateral parietal cortices and superior temporal cortices by using functional near-infrared spectroscopy. In order to investigate the relationship between the position of visuospatial attention and the cortical activities, the recently developed technique using continuously modulated visual stimuli and differential neural responses (Tajima et al, 2010) was introduced. Subjects performed the RSVP task detecting number figures among the 12 alphabets circularly arranged 4.5 deg peripherally from the center fixation point. The target appeared every about 3.5 sec. The target position continuously moved clockwise around the center FP at the speed of 360° / min. The initial position of the target was right above or below the FP. The initial position was cued before the task period lasting 75 sec. The brain activity (changes of oxy-Hb concentration) was measured at 47 points covering lateral and posterior parietal cortices and parts of temporal and occipital cortices. Differential Hb changes by the initial target position were fitted by sinusoidal curves with the wavelength of 60 sec and the other parameters were optimized for each measurement point and subject. The optimized phases for all data points distributed bimodally. The measurement points with higher phase mainly distributed on the left cortical areas including PPC, STG, and LOC, while the points with lower phases mainly distributed on the right cortical areas. In the control experiment where the peripheral stimuli were neglected and the subjects performed the center RSVP task such bimodal distribution was not observed. These results suggest that there could be the neural activities related to the position of visuospatial attention in relatively higher cortical areas.

53.428 **Maintaining visual attention across abrupt spatiotemporal discontinuities: The role of feature information**

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When spatiotemporal continuity of attended objects is disrupted, object correspondence needs to be established to maintain attentional selection. Spatial configurations are insufficient for establishing object correspondence as demonstrated by impaired multiple object tracking across abrupt scene rotations. The contribution of object features for establishing object correspondence in attentive tracking is unknown. Although object features are poorly retained during attentive tracking when retention is explicitly tested, tracking performance increases if objects stay uniquely colored during movement. We report three experiments examining the impact of briefly shown feature information on maintaining visual spatial attention

across spatiotemporal discontinuities elicited by abrupt scene rotations. In Experiment 1, participants tracked 3-5 out of 10 objects in a 3D-scene lasting 6 seconds. In half of the trials we introduced abrupt scene rotations of 30° after 3 seconds. After 2.5s all objects changed their color for 1000ms, thus staying colored across scene rotations. Object colors were either unique or homogeneous. Unique object colors improved tracking across abrupt scene rotations. In Experiment 2 and 3, we manipulated whether color information was available to establish correspondence at the abrupt scene rotations. We introduced two 500ms color intervals, one before and one after the scene rotation. They were separated by 0ms (replicating the 1000ms interval in Experiment 1), 500ms, or 1000ms to the abrupt scene rotation each. Between color intervals objects were white. The advantage of unique color information was higher when unique colors were present at the time of the scene rotation. When colors were restricted to equidistant gradations of a hue of 153-207 degree in HSV color space (thus preventing verbalization strategies) the feature effect was present with colors at the time of the scene rotation only. We conclude that feature information is used to maintain visual spatial attention across abrupt spatiotemporal discontinuities.

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Visual search: Elements, cues and configurations

Tuesday, May 10, 8:15 am - 12:15 pm

Orchid Ballroom, Poster Boards 429 - 449

53.429 **Visual Search for Motion**

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This experiment explores aspects of attention and visual search using a motion paradigm. The classic visual search paradigm has been used to develop a popular theory of attention (Treisman & Gelade, 1980). This study measures the ability to search for and discriminate moving stimuli as similarity of stimuli varies by average shared shapes between target and distractors (Sun & Shevell, 2009). The aim of this study was to see how reaction times for visual conjunctive search were affected by the role of object shapes. The stimulus was a random dot kinematogram consisting of a central region and four flanking peripheral regions. The distractor regions consisted of a central region and three out of the four peripheral regions, in these distractor regions red shapes move upward and green shapes move downward. The target region consisted of one of the four peripheral regions, in the target region the red shapes move downward and the green shapes move upward. The speed of motion was 14.1°/sec. The observer's 4 AFC task was to judge which one of the four peripheral regions was the target. The results from five observers showed that as average shared shape percentage of target and distractor areas increases, the observer's reaction times increases. The mean reaction times for average shared shapes of 0%, 25%, 50% and 100% were 1.74 sec (SEM=0.10), 2.46 sec (SEM=0.11), 3.91 sec (SEM=0.19) and 4.32 sec (SEM=0.33) respectively. A one-way ANOVA with repeated measures showed that this difference in reaction time was significant, $F(3, 12) = 16.703, p < .001$. Future research will examine how performance on visual search for motion is affected by other variables including color, object size and object density.

53.430 **How do we search when things keep moving? Selection and segregation of dynamic displays in visual search**

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Recent research has shown that visual search can proceed just as efficiently through randomly moving items as through stationary items (Hulleman, PBR, 2009). Here we tested whether the visual system can efficiently segregate moving and stationary items. We spatially interleaved stationary and randomly moving search sets, and independently varied the moving and stationary set sizes. This allowed us to measure the influence of each set (defined as the reaction time by set size slope) as a function of task relevance. Stimuli were gray disks marked with white lines. We tested three types of search task: Easy Feature search for a vertical line among lines tilted $\pm 60^\circ$ (N=12); Difficult Feature search for a vertical line among lines

tilted $\pm 30^\circ$ ($N=12$); and Spatial Configuration search for rotated Ts among rotated Ls ($N=8$). Observers were asked to search for either moving or stationary targets in separate blocks. In all three experiments, we replicated Hulleman's finding that search through moving and stationary stimuli is equally efficient in terms of the effect of relevant items (all $p > .30$). The effect of irrelevant items (e.g., moving items when searching for a stationary target), however, varied with search difficulty. For Easy Feature search, relevant items (1.7 ms/item) actually had less effect on reaction time than irrelevant items (3.5 ms/item), with a trend towards stationary items generating greater interference than moving items. For Difficult feature search, search through relevant items was inefficient (23.7 ms/item), but irrelevant items were largely ignored (6.7 ms/item). Spatial Configuration search was much more difficult (39.9 ms/item). Irrelevant stationary items were easy to ignore (2.7 ms/item), but irrelevant moving items caused substantial interference (25.9 ms/item). For very efficient searches, the target may be found before segregation comes into play. More difficult searches allow the visual system time to employ segregation mechanisms.

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53.431 **Faster is more efficient in visual search for motion**

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How does the visual system use speed to guide visual search? According to the absolute speed hypothesis, the fastest moving object in the environment will be the most salient and will be found most efficiently. This hypothesis is supported by search asymmetry studies showing that moving targets are found more efficiently among stationary distractors than vice versa (e.g., Vergheze & Pelli, 1992) and that fast targets are found more efficiently among slow distractors than vice versa (Ivry & Cohen, 1992). However, Rosenholtz (1999, 2001) argued that the multidirectional motion of the stimuli in these studies confounded the experimental design by enhancing the salience of faster-moving stimuli. She proposed an alternative relative speed hypothesis in which an object's salience depends on the difference between its speed and the speeds of other objects in the environment, regardless of which is moving faster.

In order to differentiate between these two hypotheses, we designed visual search stimuli that avoid the confound identified by Rosenholtz. In each experiment, 12 participants viewed a display of windowed square-wave gratings. While the windows were always stationary, the gratings could drift. All of the gratings in a given display drifted in the same direction. In Experiment 1, the search target moved while the distractors were stationary, or the target was stationary while the distractors moved. In Experiment 2, the search target moved either more slowly or more quickly than the distractors. In both experiments, the fastest-moving object in the environment was the easiest to detect; search slopes were near 0 ms/item. Slower-moving targets were harder to detect; search slopes were over 50 ms/item. These results support the absolute speed hypothesis over the relative speed hypothesis. The visual system appears to be biased towards the fastest moving object in the environment at the expense of slower-moving ones.

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53.432 **No Motion Filtering in Visual Search amongst Moving Items**

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Hulleman (2010) reported equal performance for easy visual search amongst static and amongst moving items. We investigated a possible role of motion filtering (McLeod et al., 1988) in achieving this robustness. Method: Participants searched for a T amongst L's. Display sizes were 12 and 18. In Experiment 1, the target and half of the distractors always moved with 7.2 deg/s. The remaining distractors moved all with either 7.2, 3.6, 1.8, 0.9, 0.45 or 0 deg/s. Half of the participants knew the target velocity. Experiment 2 contained four motion conditions (deg/s): target 7.2, all distractors 7.2; target 0, all distractors 0; target 7.2, half distractors 0, half distractors 7.2 and target 0, half distractors 0, half distractors 7.2. All participants knew the target velocity. Eye movements were recorded. Results: In Experiment 1, knowing the target velocity did not improve search performance. For both groups, reaction times on present trials became marginally faster (around 40 ms) as the velocity of half of the distractors was reduced to 0 deg/s. Reaction times for absent trials decreased around 220 ms. Experiment 2 yielded similar results. The larger decrease in reaction times for absent trials was caused by

an increased willingness to terminate search, rather than improved search efficiency due to a halving of the number of potential targets. Importantly, participants did use their instruction: average gaze distance to items moving with the target velocity was always smaller than to items moving with a different velocity. Conclusion: Neither the velocity of the search items nor velocity differences between them had a large influence on search efficiency. Hence, motion filtering plays only a very limited role when targets are not motion conjunctions. This suggests that previous results considered as support for motion filtering in visual search might be better interpreted as evidence for motion-based depth stratification.

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53.433 **On the hunt: Global biological motion information can guide attention efficiently in a visual search task**

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Biological motion is an important signal for our visual system to process efficiently and may even serve as a means to perform "life detection" (Troje & Westhoff, 2006). Using a visual search paradigm, we explored factors that influence attentional guidance by biological motion. The search targets were point-light biological motion animations depicting full body movements of recognizable actions, or scrambled versions of the same stimuli, which contain the same local but not global motion information. Targets were presented in a circular array among a cloud of three, five, or seven distractors. In Experiment 1, subjects decided whether the target was on the left or the right side of the screen. In Experiment 2, target absent trials were also included and subjects decided whether or not the target was present. In all conditions, reaction times became longer with increased number of distractors, indicating local and global information both make pre-attentive contributions to visual search. In Experiment 1, the search for the biological motion stimuli was more efficient than the search for the scrambled stimuli, but we did not observe an asymmetry in Experiment 2 (cf. Wang et al. 2010). Reaction times were notably longer in the former experiment. It is possible that local motion signals can guide attention efficiently when the task is easier, whereas global information (i.e., the Gestalt of the point-light walker) guides attention more efficiently than local information alone when the task is more difficult. Alternatively, global biological motion information may contribute significantly to attentional guidance in tasks that require locating a target, but not its detection. We will test these hypotheses, as well as the generalizability of the results to other stimuli. Presently, we conclude that global biological motion can make a contribution above and beyond local motion information to the guidance of attention in visual search.

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53.434 **How do people quit visual search? Justifications for a deadline model**

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How do people decide when to stop a search when there is no target? Most discussions on this question revolve around two models. In their simplest form, the drift diffusion model suggests that a decision is reached when sufficient evidence of target presence or absence is accumulated, and the deadline model suggests that people estimate a deadline for each search and stop when it is due. We conducted an experiment that tests against a deadline model, which assumes that search deadlines are calibrated for the observer's search experience in target-present trials. We "produced" some experimental blocks that were generally faster (or slower) by choosing more (or fewer) easy trials in these blocks, while the target-absent trials in these blocks were not censored. We expected a sooner search deadline for a "fast" block, rendering faster absent RTs. Results confirmed this expectation for large set sizes, but not for a small set size, justifying a deadline model. Analysis of data suggests that the faster absent RTs were not due to rhythmic responses. It is documented elsewhere that median absent RT generally overestimates miss rate with regard to the corresponding present RT distribution, violating the deadline model (Wolfe, Palmer, & Horowitz, 2010). However, we replicated this violation only for a small set size, but estimations based on median absent RT were very accurate for large set sizes. This mirrored the above results. In light of the present results, we suggest that observers generally adopt a deadline approach, unless a search is expedited by some evidence of an absence of target. In our case, evidence

of absence may come about when a single glimpse is sufficient to confirm all items as distractors. In other cases, uniformity of stimulus or learned statistical signals of the scene may contribute.

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53.435 An optimal termination strategy for dual-target search

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In the real world, observers may search for more than one target at the same time. For example, baggage screeners search simultaneously for very different targets (guns, knives and IED). When observers search for two targets, some studies have found that performance is worse than if observers searched for only one. Moreover, Wolfe et al. (2005) showed that error rates are strongly influenced by prevalence. Does the relative prevalence of two types of target influence observers' accuracy and quitting rules? When is it time to stop searching if there are two things to look for? Our observers performed a visual search for an oriented target. Two types of targets were intermixed in a block. On each trial, there was one target or no target. Overall target prevalence was consistently 50% within a block. One target was the "standard" type. The other type could be easy, similar, or hard relative to the standard. The relative prevalence of the two targets could be 80%/20%, 50%/50%, or 20%/80% of target present trials in a block. Results: Prevalence had its largest effect on detection of the harder target. Target absent RTs were more strongly influenced by the target pair than by their relative prevalence. Standard-Easy RTs were shorter than Standard-Hard. What principle did observers use to determine search termination time? We developed a model, based on the assumption that observers are trying to maximize the number of targets found in a fixed period of time. Observers have some knowledge of their target-present RTs and of target prevalence. Based on this information, they set a termination time. The model is quite successful in capturing the pattern of the target-absent RTs.

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53.436 The efficiency of searching for Chinese character in Pseudo characters, false characters and stroke combinations

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Fluent readers are sensitive to the lexical and orthographic properties of written words. How efficient can a native reader distinguish a real word from pseudo words (lexical sensitivity), false words (orthographic sensitivity), and stroke combinations (visual form sensitivity)? In the current study, we adopted a visual search paradigm to investigate the efficiency of lexical and orthographic information processing associated with Chinese characters. Fifteen Chinese native readers took part in this project. In the first experiment, participants were asked to search for a real Chinese character among a number of distractors. The distractors were either pseudo characters, false characters or stroke combinations which were run in separated blocks. In each search display, 3, 6 or 9 items were present. In the second experiment, target-distractor mapping was reversed and observers searched for a non-character among real characters. Results revealed large differences in the search efficiency among the three different search conditions. The slopes of search times as a function of set size for the three search conditions were significantly different. Specifically, searching for a real character among stroke combinations was the fastest (shallowest slope) while searching for a real character among pseudo characters took participants the most time (steepest slope) compared to the other two search conditions. Although overall more efficient, similar results were obtained when participants searched for non-characters among real characters. This pattern of results suggests that for Chinese characters the visual form judgment is the most efficient (real character vs. stroke combination, about 100ms per item), while the lexical processing is the least efficient (real character vs. pseudo-character, about 200ms per item), with the orthographic judgment in the middle (real character vs. false character, about 150ms per item).

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53.437 The Individual and Combined Effects of Spatial Context and Feature Cues in Visual Search

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When performing a visual search the entire visual array is typically considered relevant, and all of it must be included in search parameters. There is evidence however, that people are capable of narrowing attention to isolated spatial areas and/or visual features when those features are task relevant. In the present study we examined these two search strategies by examining their effects both individually and in combination. This allowed us to assess the manner in which the application of multiple parameters, as opposed to the use of a single parameter alone, affects visual search. Search parameters were communicated by visual cues that defined the spatial context and/or a relevant visual feature of the target. Participants were shown a random array of 36 letters and instructed to search for the target (N or X) and to indicate by button-press which target was present in that trial. Each trial was preceded by one of four cues: a featural cue, a spatial cue, a combined featural and spatial cue or no cue. These indicated, respectively, the target colour, approximate target location, target colour and location, and nothing. Analyses revealed that response times decreased for featural and spatial cue trials with respect to no cue trials, and that the combined presentation of featural and spatial cues produced a greater decrease in response times than either cue alone. These results support the assertion that people are capable of using both spatial context and visual features to improve the efficiency of their searches, possibly by directing their attention first to the relevant spatial context and then to the relevant features within it.

53.438 The Implementation of an Exclusionary Attentional Template: Direct Versus Indirect Cueing

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Observers are able to use an attentional template consisting of one, or even two, colors to guide the eyes to matching objects in a search array. We tested whether an exclusionary attentional template could be used to guide eye movements away from, and thus exclude from search, known irrelevant items. Eye movements were recorded during a visual search task in which observers searched for a Landolt-C target in a 16-item array. The array items were divided into four each of four different colors. A cue at the beginning of each trial indicated which color(s) were and were not relevant for search. When the cue depicted a color that would not be the target color, observers' first few eye movements were nevertheless directed to items that matched that color. This capture effect was plausibly driven by the maintenance of the to-be-excluded color in visual working memory (VWM). To test this hypothesis, a condition was included in which the to-be-excluded color was cued indirectly by displaying the three colors that could be the target item color. This latter cue conveyed precisely the same information but could be implemented by maintaining the three to-be-searched colors in VWM rather than the one to-be-excluded color. Now, observers' first few eye movements were directed to items matching the to-be-avoided color no more than predicted by chance (25%) and subsequent eye movements were directed to matching items less than predicted by chance. This indicates that observers are able to exclude known irrelevant items from search when all potentially relevant colors are cued. Results from the current study suggest that it may not be possible to implement an exclusionary attentional template when the to-be-avoided feature is active in VWM. However, when the color to-be-avoided is cued indirectly, our results suggest an exclusionary attentional template can be employed efficiently.

53.439 Parallel learning of multiple target locations in contextual cueing

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Contextual information can provide an important source in predicting relevant goals for behavioral orienting. For example, in visual search, detection of a target is faster when a layout of nontarget items is repeatedly encountered, as compared to search within novel item arrangements. These results show that contextual invariances can implicitly guide attention to the target location (contextual cueing; Chun & Jiang, Cogn. Psychol., 1998). Here, we explored how contextual cueing can adapt to environmental changes. A series of experiments were performed in which observers learned to associ-

ate a given repeated context with a given target in an initial learning phase. Then, in a subsequent test phase, location (and task) changes were introduced to the target. The results showed that contextual cueing could not compensate for unpredictable changes of the target location. By contrast, robust adaptation occurred when a change was predictable (i.e., learnable), suggesting that a given learned context can be “remapped” and adjusted to novel requirements (Conci, Sun & Müller, *Psychol. Res.*, 2011). Subsequent experiments demonstrated that target location changes are only effectively remapped when both the initial and the future target positions are stable and remain predictable across the entire experiment. Otherwise, contextual remapping fails, demonstrating that target locations mutually interfere with each other. In sum, this pattern of results suggests that multiple, predictable target locations can be learned and associated in parallel with a given repeated context, allowing the flexible adaptation of previously learned contingencies to novel task demands.

53.440 Signal Detection Evidence for an Attentional Bottleneck in Spatial Configuration Visual Search

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Do we need to assume capacity limitations to explain visual search performance on simple tasks? Attention-limited models propose two qualitatively different stages of perceptual processing: an unlimited capacity preattentive stage and a limited-capacity selective attention stage. Noise-limited decision models propose a single unlimited capacity perceptual processing stage, with decision processes influenced only by stochastic noise. For briefly presented displays, these two approaches can be modeled in a signal detection framework as different decision rules evaluating signal and noise. Consider two decision rules: Under a MAX rule, all items are processed with unlimited capacity and the maximum-value item is selected, while under a LIMITED CAPACITY rule, only a subset of items can be processed in a brief exposure and the MAX rule is applied to the subset.

In two-stage models, a MAX rule would govern stimuli that can be processed preattentively (e.g., feature searches) with a LIMITED CAPACITY rule required for other stimuli (e.g., spatial configuration searches). One stage, noise-limited models would either propose one decision rule for all stimuli (e.g. MAX) or must explain why different rules are required for different stimuli.

Five observers searched for either a tilted line among vertical lines or a 2 among 5s. Performance over all set sizes was equated for the two displays by varying superimposed noise. Task and relevant set size (1, 2, 4, or 8) were randomly intermixed to prevent observers from adopting different strategies for each stimulus. With stimuli thus equated, any single rule would predict essentially the same accuracy by set size function for both tasks. Two rules predict a crossover interaction with the 2v5 task easier than feature search at set size 1 and harder at set size 8. This crossover pattern was seen in the results, consistent with two-stage models and requiring a modification of one stage models.

Acknowledgement: National Institutes of Mental Health (Grant #MH56020 to JMW) and Air Force Office of Special Research (Grant #FA9550-06-1-0392 to JMW)

53.441 Interaction between depth and ocularity features in attentional attraction during visual search

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An eye of origin singleton, e.g., a single bar shown to the left eye among many identical bars shown to the right eye, can attract attention more strongly than an orientation singleton (Zhaoping, 2008 *Journal of Vision* 8(5):1, 1-18). More generally, when input strengths of an item to the left and right eyes are CL and CR respectively, contrast in ocularity (defined as CL - CR) between an item and its neighbors increases this item's saliency (Zhaoping, 2010, *Perception* 39, ECVF Abstract Supplement, p4). When input items have non-zero disparities, ocularity is generalized to relate different image locations (for each item) in the two eyes. We investigate in more detail saliency by unique ocularity when different items in a display have different depths. Subjects do visual search for a target defined as the one having a unique feature (e.g., orientation) other than ocularity and depth.

The target is easier to find when it is also an ocularity singleton (having a unique ocularity among non-targets of uniform ocularity) than the case when all items have the same ocularity. In contrast, the search is more difficult when a non-target is an ocularity singleton. These effects are significant when the ocularity contrast between the ocularity singleton and the other items is sufficient. They suggest that the ocularity singleton attracts attention to itself, thereby facilitating or interfering with the search, consistent with the theory that V1 creates a bottom-up saliency map (Li 2002, *Trends Cog. Sci.* 6:9-16). The effects persist even when the ocularity singleton is neither nearest nor farthest in depth among items of inhomogeneous depths. In at least some subjects, the non-target ocularity singleton continues to interfere with the search even when the target is in front of a depth plane containing all non-target items.

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53.442 Learning to perform efficient visual search: From inefficient search to pop-out in one week

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Search for a conjunction of visual features is generally slow and inefficient. Here we show that with practice, feature conjunctions pop out: visual search for them becomes rapid and efficient. Participants completed multiple experimental sessions (approx. 5 minutes each, a day or more apart). They viewed a circular array of disks that were green on the left and red on the right. One stimulus, the target, was reversed. While fixating, subjects searched as quickly as they could for the target amongst distracter stimuli. Initially, subjects were slower to detect the target with many distracters (31) than with few distracters (1). However, after one week of training, subjects identified the target as quickly amongst many distracters as amongst few distracters, though the speed of identification for few distracters did not change. Search performance then became asymptotic, after which we rotated both target and distracter stimuli 90° for some subjects and 180° for others. Performance remained asymptotic upon 90° rotation, suggesting generalization of learning. However, performance rebounded to pre-learning levels upon 180° rotation (which swapped targets for distracters and vice versa), suggesting an interference effect where the distracters (heretofore targets) popped out, necessitating active inhibitory processing. In a second experiment, we tested new subjects in a protocol like the first condition of the main experiment, but with more trials in each session (approx. 1 hour). Those subjects did not learn efficient search more quickly than the subjects in the original experiment. In total, our results suggest that inefficient visual search for feature conjunctions can be made efficient via a week of training, and that this learning can generalize to novel stimuli. However, the failure to speed learning via additional exposures in each session suggests that the mechanism for this learning is speed-limited, which provides a clue to its possible neuronal substrate.

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53.443 False Pop Out in Visual Search

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In visual search for a singleton target among two or more homogeneous distractors, pop out is usually observed, in which RTs to detect or locate the singleton do not increase with the number of items in the display. We have found several displays where the element that appears to pop out is not the singleton but rather one of the homogeneous distractors. Here we review these cases and provide evidence that such False Pop Out (FPO) results from grouping taking place among the separate elements in the display. For example, in searching a display containing two identical distractors and a single odd target, if that target groups with one of the distractors, this will leave the other distractor perceptually isolated, and so it will be the one to pop out. Researchers often assume that jittering positions of the elements in the display will prevent such grouping, but rarely is independent confirmation provided to show this technique works. FPO serves as a new diagnostic criterion for grouping and reminds us that subjects may perceive our displays quite differently from how we intend.

53.444 **Boundary conditions of the components of Priming of Pop-out**

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Visual search performance is strongly affected by what happened one moment ago: what we attended to, what we ignored and how we responded. Such effects have been studied by means of inter-trial effects in visual search, such as the priming of pop-out effect (PoP, Maljkovic & Nakayama, 1994), which shows that performance on singleton search is faster when the target and distractors features repeat on two consecutive trials than when they switch. The current literature is polarized with regard to whether PoP affects early, perceptual processing or later, response-related processes. We recently suggested a dual-stage model (Lamy, Yashar & Ruderman, 2010), which includes both a perceptual and a response-based component, and can accommodate findings that had so far been viewed as contradictory. We present new evidence that help us clarify how the perceptual and response-based mechanisms that underlie PoP interact during visual search and identify the boundary conditions of each mechanism. In the present series of experiments, we show that in singleton search (1) perceptual PoP effects are observed only when the task requires focused attention, (2) response-based processes affect performance only when target selection is difficult, namely, when target-distractor discriminability is low, (3) the characteristics of the whole display rather than of the target alone are compared across views and trigger retrieval of the associated response, and (4) the response-based component of PoP speeds motor response preparation and/or execution rather than discrimination of the response feature. We discuss what PoP can teach us about visual search, in light of the model.

53.445 **Detecting, localizing, and identifying feature singletons in visual search: Does task set influence the speed of pre-attentive processing?**

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Over the last decades, the visual search paradigm has proved to be a test bed for competing theories of visual selective attention. In a standard visual search task, participants are confronted with a display that can contain a target item amongst a variable number of distractor items, with reaction time (RT; and accuracy) being the critical performance measure(s). Interestingly, across search studies, the information necessary to decide upon the correct motor response is highly variable, for instance, information about the presence, spatial location, or, respectively, identity of the target item. Thus, the question emerges whether estimates of the time taken for (1) visual selection, (2) deciding on the motor response, and (3) executing it generalize across search tasks, or whether they are specific to the demands of a particular task set. To systematically examine this issue, we presented physically identical stimulus material in four different search task conditions (localization, detection, discrimination, and compound) and combined reaction time performance with two specific electrophysiological markers directly linkable to pre-attentive (Posterior Contralateral Negativity, PCN) and post-selective levels (Lateralized Readiness Potential, LRP) of the information-processing stream. At the behavioural level, RTs were found to be fastest for localization, slowest for compound, and intermediate for detection and discrimination responses. Electrophysiologically, this effect of task set had a strong impact on the timing and amplitude of the stimulus- and response-locked LRP (indexing motor response decisions), but not PCN (indexing visual selection), component. This dissociation clearly demonstrates that the choice of a task has no influence on the stage of pre-attentive visual coding, which mediates focal-attentional selection of the target item, whereas processes that occur after target selection are dependent on the nature of the task.

53.446 **You don't see what you expect to see: Action-effect blindness for learnt action effects in a visual search task**

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If a prepared action shares one or more features with an action-irrelevant stimulus in the environment, accurate perception and identification of the stimulus are impaired – a phenomenon that is known as Action-Effect-Blindness (AEB). For instance, while preparing an action with the left hand

(task 1), participants fail to identify a masked arrow pointing leftwards (task 2) while they still correctly identify an arrow pointing to the opposite direction (Muesseler & Hommel, 1997). Prior studies demonstrated AEB for stimuli that shared features with the proximal effects of an action. The present experiment expands these findings to stimuli that do not share features with such proximal effects but represent learnt action effects instead. In a learning phase, participants executed left and right key presses and experienced contingent action effects afterwards (an onset or offset of a letter in a visual search display). In a test phase, they prepared a left or right action and – while still holding the action in working memory – had to detect an onset or offset in the same visual search display as in the learning phase. In accordance with prior findings, detection of action-compatible effects was impaired compared to the detection of action-incompatible effects. This finding indicates that AEB is not due to interference of mere physical stimulus and response features but plays a functional role for perception in action.

53.447 **A Color in Working Memory Does Not Become a Search Target, but it Does Interfere with Color Search.**

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Previous visual search experiments show that searching for two targets simultaneously produces a dual-target cost in comparison with single-target search. This cost may reflect interference between two search target templates held in working memory simultaneously. The current experiments tested whether working memory for color relied on the same representation that guides search for color. In separate experiments, participants searched for a single target color while simultaneously holding one of the following in working memory: 1) a color patch, 2) a letter, 3) a dot pattern, or 4) an oriented bar. The results suggest that WM and search must rely on separate representations because the color held in WM did not affect the fixations to that same color during search. However, the two processes appear to be linked in some fashion because search was disrupted more when WM contained the color rather than the letter, the dot pattern, or the orientation stimulus. Overall, these results suggest that there is a close relationship between the mechanisms underlying visual search and working memory. More specifically, the resources for representing color may be used by both visual search and working memory, even though the values of the representations themselves do not interfere with each other. In addition, the results may also indicate that these resources are separate from those for representations of other types of visual information (orientations and spatial patterns).

53.448 **Can semantic information influence the guidance of attention by working memory?**

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Selective attention is guided towards stimuli matching working memory (WM)-held information in the form of simple features such as colors and shapes. Recent research suggests that semantic WM information can also guide attention. We tested whether WM-driven attentional guidance extends to more complex visual stimuli, such as everyday objects, and if semantic information from these objects can also guide attention during visual search. Participants viewed the image of an object and memorized its category, then searched for an unrelated target in a search array. After the search task, their memory for the category was tested. On exact-match trials, the viewed image reappeared as a distractor. On category-match trials, another exemplar of the memorized category appeared as a distractor. On neutral trials, none of the distractors were related to the memorized category. In Experiment 1, there were two exemplars of each category. Search times were longer on both exact-match and category-match trials than on neutral trials. In Experiment 2, there were four exemplars used for each category to ensure that participants prioritized semantic over visual information for the memory task. Search times on neutral, exact-match, and category-match trials did not differ significantly. In a third experiment, with two exemplars, participants memorized the object's image instead of its category. The results replicated those of Experiment 1. Taken together,

the findings show that attentional guidance by WM can occur with complex stimuli and suggest that this guidance is driven by visual, and not semantic, information in WM.

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53.449 Search Asymmetry and Eye Movements in Infants and Adults

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A key demonstration of the preattentive and attentive mechanisms thought to underlie the allocation of attention in adults has been the exhibition of an asymmetry in visual search. The asymmetry is characterized by search for a feature-present target amidst feature-absent distractors being more efficient and less affected by the number of distractors than search for a feature-absent target amidst feature-present distractors. Though studies have attempted to investigate this phenomenon with infants (e.g. Adler, Inslicht, Rovee-Collier, & Gerhardtstein, 1998; Colombo, Mitchell, Coldren, & Atwater, 1990), due to their methodological limitations, their findings have been unable to definitively establish the functioning of visual search mechanisms in infants as in adults. The present study, therefore, assessed eye movements as a means to examine visual search asymmetry in 3-month-olds relative to adults. Saccade latencies to a target were measured as infants and adults randomly viewed feature-present (R among Ps), feature-absent (P among Rs), and homogenous (either Rs or Ps) search arrays at set sizes of 1, 3, 5 and 8. Results indicated that neither infants' nor adults' saccade latencies to the target in the feature-present arrays were affected by increasing set sizes, suggesting that the target popped out and search was efficient. In contrast, saccade latencies to the target in the feature-absent arrays increased with increasing set-sizes for both infants and adults, suggesting that search was inefficient. The search functions were similar for infants and adults, with the exception that infants' latencies for feature-present targets were consistently greater than adults'. These findings indicate that infants exhibit a search asymmetry similar to adults, providing additional support for functional visual search and selective attention mechanisms in early infancy.

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Perceptual learning: Transfer and specificity

Tuesday, May 10, 8:15 am - 12:15 pm

Orchid Ballroom, Poster Boards 450 - 457

53.450 Basic Information Processing Effects from Perceptual Learning in Complex, Real-World Domains

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Purpose. Perceptual learning (PL) in real-world domains leads to fluent extraction of abstract relational structures but often requires years of exposure. Recent research (e.g. Kellman, Massey, and Son, 2009), however, suggests that PL in real-world learning domains, such as mathematics, can be accelerated using appropriately designed computer-based learning technology. Such efforts differ from most PL research in two ways: They involve more complex task domains, such as mathematical structures, and they typically employ realistic, domain-focused assessments, as in high-stakes standardized math tests. That PL effects drive learning gains in these situations may be inferred but has seldom been tested directly. Here, we studied PL in a complex domain and examined transfer to a basic information extraction task. Method. We trained participants for PL of abstract relational patterns in Chinese characters. Different groups were trained to classify based on either (1) overall configurations (structures), (2) common feature relations (components), or (3) non-relational information (stroke count). All groups used a common set of stimuli. After PL, we tested for changes in information extraction using a visual search task (which had been pretested before the PL phase). Search displays contained novel exemplars, involved manipulations of target-distractor similarity using structures and components, and included both heterogeneous and homogeneous distractor displays. Results and Conclusions. We found robust changes in visual search specific to the type of perceptual classification training. Structure-based classification training markedly improved search efficiency when target and

distractors shared the same structure, but only for heterogeneous distractors. For homogeneous distractors, component-based classification training produced most improvement in search efficiency. We also found improvement in search efficiency with exemplars of untrained relational categories. Results suggested that high-level PL produces changes in basic information extraction tasks, and that sensitivity induced by PL for both relational structure and specific components transfers to novel structural categories.

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53.451 Triply Dissociated Learning of Context, Target Orientation and Distractor Orientation in Visual Search

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Perceptual Learning (PL) and Contextual Learning (CL) are two types of implicit visual learning that have garnered much attention in the vision sciences. PL refers to the visual system learning to better represent (i.e. become more sensitive to) the elements (target and distractors) of the visual search. It is low level, slow to form, long lasting, specific to trained features and consistent with early visual plasticity. CL is the learning of regularities in the environment that allow better identification of the target-location in a visual search task. It is higher level, rapid to form, is in relation with the global stimulus configuration, and is also long lasting. While these two types of learning often co-occur in natural settings (for example, a bird watcher must be able to identify a bird but also need to know where to look for it), they are typically studied separately and using distinct experimental paradigms. Here we present results of a study, where we compared the operational measures of both PL for the target and the distractor orientations and CL for the repeated versus novel configurations, as they co-develop within a single visual search task. For CL, we observed improved performance (RT and accuracy) for learned compared to novel configurations. For PL, we observed improved thresholds and RTs for both trained target and distractor orientations as compared to the respective untrained ones, reflecting the specificity of PL for the characteristics of those elements. Notably, CL, PL for target, and PL for distractors were largely independent of each other and we observed no interactions between these three components of learning. Taken all together, these results suggest a triple dissociation between CL and PL for the target and the distractors and that these are distinct visual learning phenomena that have different behavioral characteristics.

53.452 Distinct mechanisms for visual shape learning at different time scales

Adrian Garcia¹(adg772@bham.ac.uk), Shu-Guang Kuai¹, Zoe Kourtzi¹; ¹School of Psychology, University of Birmingham, UK

Learning is known to facilitate our ability to perform complex perceptual tasks. Interestingly, behavioural improvements after training are observed not only after practice with highly similar stimuli that are difficult to discriminate, but also after exposure to dissimilar stimuli that can be easily discriminated. However, little is known about the mechanisms that mediate learning with difficult compared to easy stimuli. Here we investigate the time-course of learning when training involves highly similar vs. dissimilar visual shapes. Observers were asked to discriminate between radial and concentric Glass patterns, comprising oriented dipoles defined by dot pairs. We manipulated the similarity between these patterns by varying the angle of the local dipoles. Each observer participated in three sessions, each comprising test runs without feedback and training runs with feedback. Half of the observers were trained with highly similar stimuli that were difficult to discriminate (angles of 30° and 60°), while the rest of the participants were trained with easily discriminable stimuli (angles of 10° and 80°). All observers were tested with the highly similar stimuli (angles of 30° and 60°). Our results showed a distinct time-course for learning with difficult compared to easy stimuli. In particular, when observers trained with difficult stimuli, we observed long-term behavioural improvement across sessions, but no significant improvement within session. In contrast, when observers trained with easy stimuli, we observed short-term training improvement within the first session but no further significant improvement in subsequent sessions. These results suggest that training with difficult stimuli entails extensive practice that may optimize bottom-up feature learning mechanisms, while training with easy stimuli is achieved at much shorter time scales and may relate to top-down facilitation through

feedback mechanisms. Thus, our findings propose dissociable mechanisms for long- vs. short-term shape learning that depend on the context of the training task.

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53.453 Learning to See Second Order Information in Shading Patterns

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Shading patterns on a corrugated, textured surface contain two signals: first-order modulations of luminance (LM) and correlated second-order modulations of the local luminance amplitude (AM). Human vision is sensitive to both of these signals, and their alignment is beneficial as a cue to shape perception. Experienced observers see LM and AM gratings aligned in-phase (LM+AM) as shaded corrugations, and anti-phase (LM-AM) as flat reflectance changes: when the two mixtures are presented together in a plaid. First, we trained naïve observers with strong, trial-by-trial feedback. LM/AM mixes were presented in separate spatial locations and feedback consisted of a disparity defined corrugated surface superimposed on the LM+AM cue; LM-AM cues were paired with a flat surface. Performance improved to a maximum over the first hour of training, after which there was no further improvement. Even though this suggests that rapid perceptual learning occurred, when we flipped the feedback to reinforce the LM-AM cue as corrugated, observers flipped their responses without any deterioration in performance. This sudden reversal suggests that the performance benefit was at a categorical rather than perceptual level. Subsequently, we trained new observers with intermittent feedback to reinforce the perception of LM+AM as corrugated. This time, the LM/AM mixes were presented in a plaid for a brief duration (250 ms). Observers showed gradual increase in performance, over a period of 5 days, as they learned to discriminate the mixtures at a perceptual level; post-training AM thresholds were lower than pre-training thresholds. This benefit transferred to 450 rotations of the plaids, and also to plaid combination angles close to 90°, but failed to transfer to higher spatial frequencies or to non-orthogonal plaids. We conclude that the alignment of LM and AM as a shading cue can be learned perceptually, for briefly presented stimuli, given reinforcement by indirect feedback.

53.454 Specificity of learning in acquired bias for 3D rotation

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Cue recruitment studies (e.g. Haijng et al., 2006 PNAS) show that the visual system can be trained to disambiguate an ambiguous 3D rotation, such as the case of a movie of a rotating Necker (wire frame) cube. This acquired bias is specific to retinal location (Harrison & Backus, 2010 J Vis) and lasts at least four weeks. Resistance to reverse training is greater after viewing ambiguous stimuli without disparity, than disambiguated stimuli with disparity (Harrison & Backus, 2010 Vis Res; van Dam & Ernst, 2010 J Vis). This resistance was attributed to greater learning from "difficult to interpret" ambiguous stimuli. An alternative interpretation is that the ambiguous test stimuli used during reverse training resembled the ambiguous stimuli during initial training. Here we used stimuli that contained binocular disparity during reverse training, and the question was whether initial training would be more effective to block reverse learning. On Day 1, we measured participants' sensitivity to disparity using a staircase procedure. On Day 2, participants in Group A saw mostly non-disambiguated trials, the appearance of which was controlled by a few disambiguated trials (Harrison & Backus, 2010 Vis Res), and participants in Group B saw stimuli that contained disparity (1, 2, and 3 times threshold as measured on Day 1). On Day 3 both groups received reverse training on stimuli that contained disparity. If learning was specific to stimulus type, then resistance to retraining would be greater in Group B. If "difficult" or ambiguous stimuli simply cause stronger learning (or more resistant bias), then resistance to retraining would be greater in Group A. Results from four observers suggest that the second interpretation is correct, and that non-disambiguated stimuli do cause greater learning than disambiguated stimuli.

53.455 Attentional Oblique Effect When Judging Simultaneity: A Perceptual Learning Study

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Last year we reported an attentional oblique effect in simultaneity judgments (Kelly & Matthews, 2010 VSS abstract). Gabor stimuli were presented in four corners of the screen (14.55 deg diagonally from fixation) and changed orientation synchronously or asynchronously. Two were precued as targets on each trial. Participants judged whether or not the change in orientation happened simultaneously for the cued targets. Performance (d') was significantly worse for target pairs that were diagonally rather than horizontally or vertically aligned. Here we present new data and error analyses (false alarms vs. misses) demonstrating that this oblique effect when attending to simultaneity reflects erroneously integrated information from irrelevant spatial locations. That is, the oblique effect arose from false alarms, not misses. This excessive spatial integration for obliquely attended targets occurred between and within lateral hemifields, despite significantly greater temporal acuity (demonstrated by a significantly lower miss rate) in the left hemifield. Within-hemifield data were obtained by moving the fixation point from the center of the screen to either side, such that the stimuli on the screen fell entirely within either the left or the right hemifield. A perceptual learning experiment demonstrated that the effect was task specific: significant learning on the simultaneity task did not generalize to a task with identical displays wherein participants judged spatial frequency differences rather than simultaneity. This suggests different spatial integration windows for different attended features (simultaneity versus spatial frequency), even when those features are co-presented in space and time.

53.456 Perceptual learning effect underlying material categorization tasks

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Experts in appraisal of material worthiness, such as pearl appraisers, can instantaneously evaluate object's material qualities when seeing them. This raises the possibility that perception of material qualities can be acquired through repeatedly seeing objects and learning image characteristics associated with material qualities. Here we aim to examine whether learning in material categorization tasks can increase the performance, and what other visual sensitivities can be affected by the learning. The stimuli were photographs of various materials (Sharan et al., 2009) divided into 2 material groups: the glossy material group (glass, plastic, water, and metal) and the non-glossy material group (wood, paper, fabric, and stone). Two different observer groups were assigned to the two material groups respectively. In a trial of the learning, four photographs, one from each material group, were simultaneously presented for 50ms. Then the observer responded which photograph corresponded to a previously instructed material with a 4AFC procedure, followed by a correct / incorrect feedback. The learning period was 15 days, each of which included 200 trials for each observer. We also ran complementary experiments (specular, texture and color discrimination tasks) before and after the learning to examine learning effects for other visual tasks. The material categorization performances improved for both the two groups with the learning (40.9 % to 59.9 % of percent correct, in average), indicating that the material quality perception can be improved by perceptual learning as expected. In addition, the learning-related improvement of performances for the color and texture discrimination tasks was larger for the glossy material group. This difference in learning effects suggest that improvement of the material categorization performances is, at least partly, based on learning effect for the relatively lower-level visual processing associated with the image features which may underlie material categorization for each material group.

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53.457 Attentional load effects on visuo-motor learning

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To assess how attention is used during visuo-motor learning, we used a visuo-motor adaptation paradigm combined with a rapid serial visual presentation (RSVP) task. Participants reached to visual targets presented on a computer monitor using a mouse. In the null condition, the cursor followed the mouse normally, whereas in the rotation condition, the cursor direction was rotated 45° clockwise to force movement re-updating and induce learning. Participants performed 40 null (Baseline), 160 rotation (Learning), 80 null, and 80 rotation trials (Recall). In the RSVP task, participants had to detect various colored upright and inverted 'T's during the Baseline and Learning phases. Attentional load was manipulated by instructing the three groups of participants either to ignore the RSVP task (No load), detect a single feature (Low load), or detect a conjunction target (High load). Our results show that during the Learning phase, all groups performed similarly, decreasing reaching error steadily regardless of attentional load. Further, there was no difference between the groups at the end of the Learning phase. However, while the No load and Low load groups showed lower reaching error at the Recall phase, in which the rotation condition was introduced again after the null condition, than at the Learning phase, the High load group behaved like naïve participants, showing no improvement in error reduction rate compared to the initial learning block. Thus, this suggests that although attentional load does not interfere with error reduction during sensory-motor adaptation, it appears to critically disrupt memory formation, supporting a selective role of attention in motor memory formation.

Acknowledgement: Brown University startup fund

Perception and action: Locomotion

Tuesday, May 10, 8:15 am - 12:15 pm

Vista Ballroom, Poster Boards 501 - 521

53.501 Steering and Cognition: Does attentional load impede or facilitate steering around a bend?

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Steering around bends is a common task performed daily by millions of people, yet the underlying neural mechanisms remain largely uncharted. It has been proposed that steering can be performed without recourse to conscious "cognitive" control (Gibson, 1958), however, much simpler locomotor-related tasks, such as judging one's heading, have been shown to be affected by concurrent attentional tasks (Wann et al, 2000). Here we examine whether an attentional task placed at the point of fixation influences steering. Twelve participants were asked to steer around bending roadways (3m wide, radius = 60m to 35m) at a constant speed (13.8m/s). Participants fixated a sign positioned at 1 of 4 different eccentricities relative to screen and body midline (+/-30deg, +/-20deg). The sign either showed a cross (no attentional load), or numbers/arrows (attentional load). The attentional loads were similar to Wann et al (2000): i) the "Number" condition presented a sequence of two numbers, after the trial participants judged whether they were ascending or descending; ii) the "Arrow" condition presented a sequence of two arrows that pointed in different directions, after the trial participants judged whether the second arrow was oriented clockwise or anticlockwise compared to the first. In all conditions participants' steering drifted in the direction of the fixation points (consistent with Robertshaw & Wilkie, 2008), but no significant effect was found in steering bias for the three different attentional load conditions. However, in the "Number" and "Arrow" conditions steering was significantly less variable than the no-load condition. We suggest that this reduced variability reflects visuomotor 'locking' due to reduced responsiveness to visual-feedback. As such we conclude that steering can be influenced by cognitive processing, with one potential cost being reduced flexibility in steering when there is a concurrent attentional load.

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53.502 Non-visual self-motion information influences the perception of object motion while walking

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When people walk through environments containing moving objects, the self-motion and object-motion components of optic flow are additively combined. Detecting the information needed to select routes requires the visual system to recover the object-motion component by discounting the self-motion component. This experiment is part of a larger study in which we are systematically evaluating how visual and non-visual information about the direction and magnitude of self-motion contribute in recovering the object-motion component. In this particular study, we focused on the role of non-visual information about the direction of self-motion. The experiment consisted of two sessions and was conducted in an immersive virtual environment viewed through a head-mounted display. In Session A, subjects were instructed to walk along a straight path as an obstacle moved from right to left along a path that would intersect their future path. Within 1.6 s of moving, subjects judged whether they would pass to the left or right of the moving obstacle. Judgments in Session A were compared with judgments in Session B in which the conditions were identical except that non-visual self-motion information was manipulated. This was achieved by laterally displacing subjects in the virtual environment 0.4 m leftward for every 1.0 m of forward movement. Because the lateral shift manipulation was present on the majority (83%) of trials, the perceived direction of self-motion based on non-visual information was realigned. On the remaining 17% of trials in Session B, the lateral shift manipulation was removed. Conditions on such catch trials in Session B were identical to conditions in Session A except that the perceived direction of self-motion based on non-visual information was offset. For most but not all subjects (N = 16), judgments in Session B were influenced in a way that is consistent with the use of non-visual information about direction of self-motion.

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53.503 A speed control law for pedestrian following based on visual angle

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Following another pedestrian is common in everyday locomotion, and may contribute to the collective behavior of crowds. Last year we modeled the behavioral strategy for speed control in 1D following (Rio, Rhea, & Warren 2010); this year we investigate the visual information used to regulate speed. Previously, we modeled data on the follower's acceleration in response to the leader's change in speed by (a) nulling change in distance, (b) nulling the difference in speed, and (c) combining speed and distance using a ratio (Gazis, Herman, & Rothery 1961) or a linear combination (Helly 1959; Anderson & Sauer 2007). The data are well-accounted for by the relative speed model. Here, we manipulate the visual angle and binocular disparity of a virtual 'leader.' The participant followed a virtual target pole (0.2m diameter) viewed stereoscopically in a head-mounted display (63° H x 53° V) in the 12x12m VENLab. A change in target speed over a 3s interval was specified by (1) a 50% increase, decrease, or 0% change in visual angle, achieved by shrinking or expanding the pole, and (2) a 50% decrease, increase, or 0% change in binocular disparity. The visual angle and disparity conditions were fully crossed, so that the changes could be congruent or incongruent. Participants' mean speed during the manipulation showed that they relied entirely on the change in visual angle (p < .001) and ignored the changes in disparity (ns). We combine these results to derive a speed control law for following, in which the follower matches the leader's speed by nulling change in their visual angle. Future work will expand the following model to the general 2D case, in which the leader changes direction as well as speed (Rhea, Cohen, & Warren 2009), and will investigate its role in crowd behavior (Rio, Bonneaud, & Warren 2010).

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53.504 **Corrective response reaction times and multi-motor coordination after countermanding failures**

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Operating in a dynamic environment often requires inhibition of responses. Countermanding tasks have been used extensively to probe the mechanisms behind inhibition. We used a countermanding task to investigate the processes at play during failure of inhibition. Specifically, we investigated the reaction times for correcting mistakes. Participants were instructed to respond to a 30° visual target presented randomly left or right of central fixation by orienting their eyes, head, and arm to the target. A visual stop signal was presented in 30% of the trials at central fixation, 25, 75, 125, 175 or 225ms after target appearance and prompted participants to cancel their response. In case of inhibition failure, participants were instructed to reorient all effectors back to center. Reaction times (RT) and times to correct a failed stop (CRT) were measured for all effectors using video eye tracking (Chronos Vision), 3D infrared marker tracking of the head and arm (Optotrak), and electromyography of shoulder and neck muscles (DeSys EMG). Estimated stop signal reaction times (SSRT) measured the efficiency of response inhibition. The RT distributions and SSRTs of all effectors were consistent with predictions from a dual LATER model describing a race between a 'go' and a 'stop' process. We extended this model to capture CRT distributions. We found a delay between the end of the go/stop race and the corrective response onset. This delay could be characterized by a second 'go' process starting after the previous stop signal reached threshold. Correlations of latencies (RTs and CRTs) between effectors suggest a supervisory control mechanism for both initial and corrective responses, pointing towards effector-specific decision processes receiving input from the common controller. Our results demonstrate that correcting incorrect responses relies on processes similar to the ones governing response initiation and inhibition and that this is true across all effectors.

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53.505 **Visual control strategies for the interception of moving targets on foot**

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Navigating through complex, dynamic environments requires people to select actions and guide locomotion relative to moving objects. When people intercept moving targets on foot, their behavior is consistent with a constant bearing angle (CBA) strategy, according to which interception is achieved by moving so as to keep the target at a fixed bearing angle. However, the CBA model does not explain how direction and speed of locomotion are coordinated during interception, nor does it account for the ability to perceive whether interception is even possible given the person's movement capabilities. In this study, we introduce an alternative to the CBA model that offers a starting point for addressing these limitations and accounts for findings from previous studies that were difficult to reconcile with the CBA model. The new model is based on eyeheight-scaled information that specifies the locomotor speed (in units of eyeheights per second) needed to intercept the target as a function of the direction in which one intends to move. In Experiment 1, we tested the predictions of the new model by manipulating eyeheight, which should affect walking trajectories if subjects rely on eyeheight-scaled information but not if they use a CBA strategy. Subjects walked in a virtual environment viewed through a head-mounted display to intercept targets that appeared on the left or right side and moved inward. Target speed and trajectory varied across trials. Analyses focused on walking speed and direction in the control and reduced-EH conditions. In Experiment 2, we tested another prediction of the new model—that the perceived walking speed needed to intercept the target should be affected by manipulations of visual self-motion information. This prediction was tested by manipulating subjects' movement relative to the stationary background in the virtual environment without affecting their movement relative to the moving target.

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53.506 **Effects of physical acceleration in the perception of induced self-motion by a real world display**

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[Purpose] It has been well known that the perception of self-motion, especially linear vection, is induced by a visual stimulus under a condition that there is no information of physical acceleration along a direction of self-motion induced by an optical flow in a visual stimulus. That is, in most of cases, it is not necessary for gravity to be taken into account as an acceleration cue because its direction is the orthogonal to a moving direction. We investigated whether this condition as to acceleration is mandatory for the perception of vection. [Experiment] To test effects of physical accelerations in parallel to a moving direction in the perception of a linear vection, we measured duration of a delay (latency) up to the perception being induced. We used real world displays, edited commercial movies such that an observer is looking at around rails when sitting down in front of a train, because it is known that a real world display induces the perception more effective than more abstract one does. We varied a speed (114.1 to 342.3 km/h in the depth direction), and a direction (expansion and contraction, i.e., forward and backward locomotion) of optic flow in the real world display under conditions of a direction (same or opposite) of acceleration to a direction of the induced self-motion. [Result and Discussion] In contrast to our expectation, all observers perceived the linear vection under all experimental conditions in the real world display, although the latencies up to perceiving the vection were much longer than those to the conventional vection displays. The latency under the condition of the opposite direction of the acceleration was shorter than that under the same direction condition. These results suggest that inconsistent information of acceleration (the opposite to a moving direction) enhances to induce the perception of the vection.

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53.507 **On-line and off-line control of locomotion: Steering a slalom course**

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The steering dynamics model of human locomotion (Fajen & Warren, 2003) demonstrates that steering could be controlled on the basis of current visual information, without relying on an internal path plan or model of the environment. To investigate whether locomotion is under on-line or off-line control, participants walked a slalom course of five goals while viewing conditions were manipulated. Virtual displays of goal poles (1.44m high, .12m diameter) standing vertically on a ground plane were presented stereoscopically in a head-mounted display (63°H x 53°V) in the VENLab (12m x 12m), while head position was recorded. The task was performed under five viewing conditions: (1) FullView: all goals in the slalom course were visible. (2) Preview1: only one goal immediately ahead of the participant was visible. (3) Preview2: the two goals immediately ahead were visible. (4) Block1: all goals were visible except the two immediately ahead. (5) Block2: all goals were visible except the two immediately ahead. If the path of locomotion is planned in advance or based on an internal world model, one might expect steering to improve with a longer preview; more critically, the effect of occluding the next couple of goals should be minimal. Analysis of passing errors indicated that steering was no more accurate or precise in the Full View than the Preview 1 condition (ns), indicating no advantage of a longer preview. In contrast, performance significantly deteriorated as visual information about the next one or two goals was removed (p<.001). This pattern of results is consistent with the view that human locomotion is controlled on-line based on current visual information about the next one, or possibly two, goals.

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53.508 **Overestimating action capabilities for passing through vertical and horizontal gaps under severely degraded vision**

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Successful spatial navigation involves the ability to perceive architectural features, such as arches and doorways, as they relate to the possibility of future actions. While navigating spaces, low (degraded) vision individuals may rely on assumptions about architectural features that are consistent with their expectations and previous experience. However, horizontal and vertical gaps (e.g., open stairs, bollards) can vary greatly from one environment to another, potentially posing a navigation hazard. When architectural features are inconsistent, low vision individuals may have to rely more heavily on online visual perception than their expectations. To determine action possibilities, an actor must compare environmental features (e.g., gap width) to relevant body effectors (e.g., body width). In the present studies, participants judged their abilities to pass through horizontal and vertical gaps. They first made these judgments while wearing monocular goggles that reduced acuity and contrast sensitivity and then with monocular goggles allowing otherwise normal vision. Two black poles in front of a white background were presented to participants creating various horizontal gaps. Participants judged yes or no to whether they could pass between the poles without turning their shoulders. Participants also judged yes or no to whether they could pass under a horizontal barrier without needing to duck. The barrier was black and hung in front of a white background. For analysis, judgments were compared to actual body dimensions. Findings indicated that participants made less conservative estimates of action capabilities under low vision conditions than under normal vision conditions. That is, under low vision, participants said they could pass through narrower widths and shorter heights than they reported for normal vision. A study with reverse contrast sign stimuli (white objects in front of black background) is in progress. The inability to correctly perceive environments is a potential safety hazard; this research could inform architecture building guidelines.

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53.509 **Age-related differences in detection of collision events on linear trajectories**

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Previous studies found age-related differences in judging time to contact (TTC), assuming the occurrence of impending collision events. DeLucia et al. (2003) pointed out that judgments of the occurrence of collisions should be made prior to judging when collisions would occur. Andersen and Enriquez (2006) found age-related declines in collision detection sensitivity, particularly for increased speed, shorter display durations, and longer TTC conditions. One important question remains unclear is whether the vehicle's speed would affect a drivers' sensitivity to collision events. In the current study, we examined the effect of ego-speed on collision detection between younger and older observers. The constant expansion rate information was achieved by keeping the relative speed between object and observers constant. The independent variables include display duration (3 or 7 sec with constant TTC of 9 sec) and ego-speed (24, 36, or 48 km/h). 22 younger adults (mean age of 20.3) and 21 older adults (mean age of 79.1) participated in the experiment, in which they were presented with displays simulating a single approaching object in the 3D scene. The results showed declines in collision detection sensitivity for older observers, as compared to younger observers, particularly with decreased display duration and increased speed. However, older adults performed as well as younger adults in longer display duration (7 sec) even at high ego-speed (48 km/h). Overall, the results suggest older observers have more difficulty detecting collision object within limited time, as compared to younger observers, particularly at high ego-speed. In other words, older drivers need more time to successfully detect an imminent collision object, which indicates less time is left for them to take effective controls thus resulting in increased crash risks.

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53.510 **Retinal information influencing heading perception during rotation**

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It has been reported that humans can accurately perceive heading during simulated eye rotation using information from optic flow alone. Here we investigated what roles spatial frequency content, surface structure, foreground motion, and expansion information play in heading perception during rotation. The display (110°Hx94°V) simulated an observer walking on a straight path over a ground plane (depth range: 1.4-50 m) at 2 m/s while fixating a target off to one side (mean R/T ratios: ±0.8, ±1.6, ±2.4) under six display conditions, in which (1) 50 random dots were uniformly distributed on the ground plane; (2) the same number of dots was placed at each distance in depth to increase foreground motion; (3) the dots were uniformly distributed on the image plane to remove static depth cues; (4) the ground plane was replaced with the lower half of a 3D random-dot cloud that had the same velocity profile as (3) to remove the surface structure defined by dot motion in (3); (5) a ground similar to (3) but consisting of discs that expanded during the trial; and (6) a textured ground having the same spatial frequency power spectrum as (5). At the end of each 1s trial, observers used the mouse to indicate their perceived heading along a horizontal line in the center of the display. Mean heading bias was significantly smaller for (6) than for (5), indicating that spatial frequency content is not crucial for accurate heading perception during rotation. Mean heading bias was similar for (3), (4), and (5), indicating that expansion and surface structure information do not affect heading perception. Lastly, mean heading bias was borderline significantly smaller for (2) than (1), revealing that foreground motion plays a modest role in accurate heading perception. We conclude that dense motion parallax information is most important for accurate heading perception during rotation.

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53.511 **Age-Related Differences in Steering Control under Deteriorated Optical Flow Conditions**

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It has been well documented that declines in perceptual and cognitive abilities emerge as we age. As a result, older drivers have significantly increased accident risks, especially under low visibility conditions such as at night or in fog. Research has shown optic flow is a useful source of information for performing driving tasks such as perceiving heading direction and self-speed. However, there has been little research examining age-related differences in processing optic flow information, specifically under deteriorated conditions. The current study investigated this question by manipulating both the quantity and the quality of optical flow information. Twenty-two young ($M = 20.9$ years) and 17 older ($M = 78.1$ years) drivers were presented with displays simulating driving through a 3D array of dots randomly located on a ground plane. The lateral position of the vehicle was perturbed by the simulated side wind gust according to a sum of three sinusoidal functions. Deteriorated optic flow information was achieved by reducing the quantity of dots (125, 25) and the quality of the dots (high, medium, and low contrast). Driving performance was evaluated by computing the root mean square of the deviations between vehicle position and designated straight path. A three-way ANOVA analyses showed significant main effects of dot number, dot contrast, and age. Overall, more steering error was found with decreased dot number and decreased dot contrast for both age groups, with better performance for younger participants as compared with older participants. Further, the results suggest that older participants suffer more from decreased quality and quantity of optical flow information. Overall, the results indicate increased accident risks for older drivers under deteriorated optical flow conditions. To address this issue, it is necessary to improve the roadway environment, or develop driving assisting systems accommodating age-related deficit in driving safety, especially under low visibility conditions.

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53.512 Perceiving path from optic flowJoseph Cheng¹(jckcheng@hku.hk), Li Li¹; ¹Department of Psychology, The University of Hong Kong

We have previously shown that when traveling on a circular path, observers did not rely on flow lines or vector normals to perceive the path trajectory of their traveling from optic flow. Furthermore, they could not perceive path rotation from the change of heading when retinal flow did not contain rotation. Here we further investigated this topic. In Experiment 1, the display simulated an observer traveling on a circular path (curvature: $\pm 0.017\text{m}^{-1}$, $\pm 0.026\text{m}^{-1}$, & $\pm 0.035\text{m}^{-1}$) over a textured ground or a textured ground with 20 posts (depth range: 5-20m). The simulated observer gaze direction was pointed to a target (1) on the path at 30° away from the initial heading, (2) at 15° outside of the path, (3) at 15° inside of the path, or (4) along the Z-axis of the simulated environment. Consistent with our previous findings, path performance was not accurate and was affected by path curvature for all viewing conditions. Furthermore, path performance was similar for the two display conditions, indicating that reference objects do not help path perception. In Experiment 2, instead of pointing to the target, the simulated observer gaze direction pointed to heading thus the target moved on the screen rendering pursuit eye movements. Compared with data from Experiment 1, path performance was more accurate and less affected by path curvature, indicating that extra-retinal signals improved path perception. In Experiment 3, observers were asked to estimate path rotation using a 2AFC task for the four viewing conditions with the textured ground display from Experiment 1. Path rotation estimation errors were highly correlated with path perception errors observed in Experiment 1. We conclude that observers estimate path curvature using their perceived path rotation and then perceive path relative to their heading. Extra-retinal information helps observers accurately estimate path rotation and thus contributes to accurate path perception.

53.513 Improved steering performance with enhanced recruitment of the superior parietal lobe: An fMRI study.Jac Billington¹(jaclyn.billington@rhul.ac.uk), Richard Wilkie², David Field³, John Wann¹; ¹Department of Psychology, Royal Holloway, University of London, ²Institute of Psychological Sciences, Faculty of Medicine and Health, The University of Leeds, ³Centre for Integrative Neuroscience & Neurodynamics, School of Psychology and CLS, University of Reading

Navigating successfully through the environment typically involves both detection of current egomotion as well as anticipation of impending changes in heading trajectory. Here we build upon our previous finding of increased activation in a region of the superior parietal lobe (SPL) and the medial intraparietal sulcus when future path information allowed for greater anticipation of heading response. In the present study we use a slalom steering paradigm, which required participants to navigate around objects in a virtual world using a joystick in the fMRI scanner. Future obstacles were either all revealed to the participant at the start of the trial in steering preview trials (allowing for future planning), or revealed one by one with an impending obstacle being revealed when the current obstacle was being passed in steering near trials (initiate steering only ~2sec before the object would be reached). These active steering trials were matched in terms of motor requirements and visual properties using passive heading (preview and near) trials in which participants were replayed their previous steering trials and merely had to mimic their virtual heading. Results confirmed SPL recruitment during steering trials, with a more extensive network during steering preview compared to steer near trials. Correlational analysis of fMRI data with respect to individual behavioural performance revealed that there was increased activation of an anterior (and partially overlapping) region of the SPL in participants who exhibited smoother steering performance. These findings are interpreted in terms of a role for the SPL in spatial encoding and updating of future targets or obstacles during forward locomotion, and a potential neural underpinning for improved steering performance on an individual basis.

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53.514 Does Locomotion Enhance the Visual Accessibility of Ramps and Steps?Tiana M. Bochsler¹(bochs001@umn.edu), Christopher S. Kallie¹, Gordon E. Legge¹, Rachel Gage¹, Muzi Chen¹; ¹Psychology Department, University of Minnesota, Twin Cities

Visual accessibility is the use of vision to travel efficiently and safely through an environment, to perceive the spatial layout of the environment, and to update one's location in the layout. The present study extends the findings of Legge et al. (J. Vis., 2010) who described the effects of lighting, geometry, and surface properties on the recognition of ramps and steps by stationary subjects. Since locomotion can provide information about surface depth and orientation, the current investigation explores whether locomotion toward a ramp or step might enhance recognition accuracy. Twelve normally sighted young adults viewed a sidewalk interrupted by one of five possible targets: a single step up or down, a ramp up or down, or flat. Subjects reported which of the five targets was shown, and percent correct was computed from a block of trials. Subjects viewed the targets monocularly through goggles with an effective acuity of ~20/900 (severe blur). They made target recognition judgments from distances of 5 ft or 10 ft either after stationary viewing or after walking 10 ft to the same viewing locations. In the texture condition, the sidewalk was covered with a high-contrast checkerboard pattern, surrounded by black walls and flooring. In the plain condition, the sidewalk was uniform gray. Subjects recognized ramps and steps significantly more accurately in walking trials (64%) than in stationary trials (58%), $p < .05$. Consistent with our previous results, ramps and steps were more accurately recognized overall with the plain floor (65%) than the textured floor (56%), but this difference was not statistically significant for the walking trials. We conclude that locomotion enhances the visibility of ramps and steps, and may enhance visual accessibility for people with low vision. Locomotion may also partially negate the deleterious effects of misleading floor-texture features.

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53.515 Are Older Adults' Actions Affected by Their Perceptions When Walking Through Apertures?Amy Hackney¹(hack7780@mylaurier.ca), Michael Cinelli¹; ¹Wilfrid Laurier University

Perception and action are coupled such that actions within an environment change the perceptions of the objects within the environment (Gibson, 1979). Likewise changes to an individual's action capabilities (balance) affect his or her perceptions (Geuss & Stefanucci, 2010). The objective of the current study was to determine if previously observed age-related differences in actions (Hackney & Cinelli, 2010) were due to differences in perception. Our hypothesis was that age-related differences in balance stability lead to differences in perception that in turn produce differences in actions. Young ($n=10$) and older adults ($n=6$) performed 3 blocks of trials (static perceptions, dynamic perceptions, & action). The first two blocks were counter-balanced and required the participants to give a yes/no response as to whether they could pass through an aperture (0.9-1.8 times shoulder width) without rotating their shoulders. Both perceptual judgements were made 5m from the aperture either standing or approaching the mark from 9m away respectively. The action block required participants to walk down the 9m path at a self-selected pace and pass through the aperture (1-1.8x SW) using a suitable method. Action results revealed that older adults begin to rotate shoulders at larger apertures than young adults (~1.6 and ~1.4x SW respectively, $p < 0.05$). Perception results revealed that static perceptions were not different between young and older adults, however, older adults had more conservative dynamic perceptions ($p < 0.05$). Therefore, it is possible that the decreased dynamic stability of older adults leads to changes in dynamic perception causing more cautious actions.

53.516 Inconsistent Routes in Moving Obstacle Avoidance Are Due to Sensitivity to Initial Conditions, not AttentionHenry S. Harrison¹(henry_harrison@brown.edu), William H. Warren¹; ¹Department of Cognitive, Linguistic, and Psychological Sciences, Brown University

The steering dynamics model of human walking (Fajen & Warren, 2003) was developed to account for paths of locomotion with a single goal and a single obstacle (either stationary or moving). If locomotor behavior scales with the complexity of the environment, then a linear combination of the model's (nonlinear) terms should generalize to more complicated scenes. However, Cohen, Bruggeman, & Warren (VSS 2006) reported that human

routes with two moving obstacles were surprisingly inconsistent. One explanation is that inconsistent routes are due to sensitivity to initial conditions, a hallmark of complex nonlinear systems. Another is that they result from differences in the allocation of attention during locomotion. Here we manipulated the attended object during walking in a virtual environment (the VENLab). Participants avoided two moving obstacles en route to a stationary goal. In the fixation condition (N=16), the participant started walking to the goal, after 1 m the obstacles appeared, then one object flashed to indicate the fixation/attention target: (i) near obstacle, (ii) far obstacle, or (iii) goal. In the free fixation condition (N=16), participants received no fixation instructions and no objects flashed. Observed routes were significantly more consistent in the fixation condition (86% > 78% matching the preferred route). However, this is attributable to two fast participants in the fixation group. Model simulations that incorporated the initial conditions of each trial (speed, position, heading when obstacles appeared) exhibited a similar improvement in consistency (84% > 73%) and predicted the observed route on individual trials with equal success (65%). The results demonstrate that inconsistent routes are primarily due to sensitivity to initial conditions in human locomotion, not to differences in the allocation of attention. The steering dynamics model thus generalizes to more complicated scenes, although its predictiveness on individual trials is limited by biological noise near bifurcation points.

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53.517 Vection stimuli placed on a road modulate driver's speed sensation in a real driving scene

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It is well known that moving dots, e.g., expanding toward the eye, in a display may induce linear forward vection to the stationary observer. It is not clear, however, whether a series of real flickering lights, arranged along a road producing apparent motion, could work as vection inducing stimuli to modulate the driver's speed sensation. In this study we examined this possibility of the vection effects in a real driving scene. 3D freeway-driving movies were presented as test scenes on a hemisphere-screen of 8.5m diameter which produced a wide visual field of 120deg. The vection inducing stimuli consisted of the flickering poles placed on both sides of a freeway in the driving scene. These vection inducing stimuli produced apparent motion toward the driver with various speeds. Observers compared two successively-presented scenes with and no vection inducing stimuli, and chose the scene where observers had faster speed sensation. The scenes with no vection inducing stimuli served as references. The size of the poles, interval distance of the poles, and various traffic environments in the freeway were the experimental variables. Twenty five observers participated in the experiment. The results showed that the flickering poles on a road could increase consistently driver's speed sensation with the speed of apparent motion regardless of the size of the pole and traffic environments. But reducing interval distance of the poles decreased the driver's speed sensation. These findings suggest that, on a real freeway, a series of flickering poles could be a new and effective tool to control the speed of cars by changing the speed sensation of drivers.

53.518 Visual control of steering toward a goal

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We examined the use of heading, path trajectory, tau-equalization, target drift canceling, and target egocentric direction strategies in visual control of steering toward a goal. The display (110°Hx95°V) simulated an observer walking over a ground plane at 2 m/s. Observers used a joystick to change the curvature of their traveling path to steer toward an environmental target under two display conditions (sparse flow: the ground was composed of random dots; dense-flow: the ground was textured). In Experiment 1, the simulated observer gaze direction was fixed on the target. The target position was thus fixed on the screen and observers could not perform the task by canceling the target drift or centering the target with respect to their perceived straight ahead. Observers did not rely on the tau-equalization strategy (equate the time-to-closure and the time-to-passage) or a path-based strategy (point their expected path at the target) to perform the task. Instead, observers steered their heading toward the goal with a shorter response delay for the dense than the sparse flow displays. In Experiment 2,

the simulated observer gaze direction was fixed at 10° to the left or right of the observer's instantaneous heading. The target thus moved on the screen during steering control. Three groups of observers were tested with one group instructed to steer toward the target, one group to steer to center the target with respect to their perceived straight ahead, and one to steer to cancel the target drift. Steering to cancel the target drift generated a different pattern of performance data from steering toward the target or to center the target. Mean final heading errors for the latter two tasks were similar and significantly less than 10°. We conclude that humans use both heading and egocentric direction strategies in steering toward a goal and discrepant optic flow can adapt our perceived straight ahead direction.

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53.519 Visual control of foot placement when walking over rough terrain

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When people walk over rough terrain with obstacles to step over and irregularly spaced safe footholds, they must carefully choose their footsteps in a way that allows for forward progression while maintaining dynamic stability and minimizing energetic costs. The role of continuously available visual information when stepping over a single obstacle or onto a single target has been investigated in previous studies. When stepping over multiple obstacles, however, proper foot placement depends not only on the next obstacle but also on the size, position, and orientation of future obstacles. The goal of the present study was to investigate how far ahead along the future path visual information is needed to control foot placement. We developed a novel experimental paradigm in which subjects walked over an array of randomly distributed virtual obstacles that were projected onto the floor by a LCD projector while their movements were recorded using a full-body motion capture system. In the control condition, the entire array of obstacles was visible to subjects as they walked the length of the path. In other conditions, obstacles did not appear until they fell within a window of visibility centered on the subject's head. The size of the moving window was manipulated across blocks of trials. Walking behavior in each condition was compared to the control condition to estimate how far ahead along the upcoming path people need to see to avoid stepping on obstacles and to maintain forward progression and dynamic stability. Several measures of walking performance were computed, including walking speed, number of collisions, and the margin of dynamic stability. Data from three subjects show a strong effect of viewing distance on measures of walking performance, suggesting that visual information from several steps ahead is used to control foot placement when walking over rough terrain.

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53.520 Age differences negotiating paths of different widths at different speeds: does old age mean "middle of the road"?

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Skilled movements deteriorate with increased age for well-documented physiological reasons. Reduced sensory sensitivity and biomechanical attenuation can interfere with motor function making older adults more variable in their responses. We examined the degree to which older adults manage to compensate for this increase in visual-motor variability when carrying out two skilled actions: tracing and steering. In both cases, participants generated trajectories within the boundaries of a delineated path. When tracing, the participants used a handheld stylus to follow a sinusoidal shape displayed on a tablet laptop. When steering, participants used a steering-wheel to change their locomotor direction to match a perspective-correct computer-generated sinusoidal roadway (see Wilkie & Wann, 2003). Three different path widths were used (2, 4 or 6mm in tracing; 2, 4 or 6m in steering), as well as two speeds (slow was half the fast speed). In the tracing task participants could also move at their preferred speed on 1/3 of trials. Older participants were more variable but compensated for their increased motor variability by being slower (when possible) and staying further away from the road edges (i.e. sticking to the "middle of the road"). This meant that although on wider paths the older participants were able to meet the task requirements (stay within the boundaries) on narrow paths their performance deteriorated (especially at fast speeds). In contrast, the young were able to be more accurate on narrow paths whilst moving faster and cutting corners on wide paths (presumably as a function

of their lower variability). Our results show that compensation strategies generalise across two different visual-motor tasks (tracing to steering) and reveal fundamental mechanisms underlying skilled performance in the human action system.

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53.521 **Two Modes of Motion Perception: A Double-dissociation of the effects of contrast and field of view on perception of object-motion and self-motion**

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Several studies have shown that reduced contrast causes an illusory reduction in the perceived speed (e.g., Thompson, 1982). However, a more recent investigation of driving behavior found no effect of reduced contrast on drivers' perception and control of their vehicle's speed (Owens, Wood, & Carberry, 2002, 2010). This empirical discrepancy raised the question of whether the illusory changes in perceived speed with reduced contrast are specific to object motion. To answer this question, we tested the effects of reduced contrast and limited field of view (FOV) on visual perception of (a) object-motion and (b) self-motion. In Experiment I, participants matched the apparent speed of two rotating textured disks. Like the "Thompson Effect," reduced contrast produced a significant decrease in perceived speed of rotation. Perceived speed was not affected, however, when FOV was reduced to 5°. In Experiment II, posture and vection were recorded while participants viewed the interior of a large rotating drum, which created roll vection. Unlike the "Thompson Effect," reduced contrast had no effect on perception of self-motion or posture. Vection decreased significantly, however, when FOV was reduced to 5°. These results represent a double dissociation of two modes of motion perception: Contrast affects perception of object-motion but not perception of self-motion; whereas, reduced FOV affects perception of self-motion but not perception of object-motion. Consistent with previous investigations of the effects of blur and reduced luminance on vection and vehicle control (Leibowitz, et al., 1979; Owens, et al, 1999, 2007, 2010), the present findings add evidence for two functionally distinct "modes of vision:" a focal mode that mediates object perception and an ambient mode that mediates perception of posture and self-motion.

Object recognition: Experience and learning

Tuesday, May 10, 8:15 am - 12:15 pm

Vista Ballroom, Poster Boards 522 - 533

53.522 **Visual benefits from auditory statistical learning: The case of reading**

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Statistical learning (SL) may be important for language acquisition, as revealed by enhanced auditory word recognition following learning. However, language extends beyond audition, being fundamentally dependent on vision in numerous ways, including reading, writing, gestures, and sign language. To what extent does auditory SL in speech streams influence visual language processing? Previous research on audiovisual SL has found a lack of transfer between modalities for underlying grammars, emphasizing that SL operates in a stimulus-specific manner. Here, we test the transfer of stimulus-specific SL, where stimuli are spoken during familiarization and then written during test. Observers were familiarized with a five-minute-long auditory syllable stream that, without their knowledge, was constructed from four tri-syllabic words. There were no pauses or prosodic cues to indicate boundaries between words, and thus any resulting word knowledge reflects SL. Learning was tested using a speeded reading task in which observers read text on a computer screen aloud and pressed a key when finished. They completed six test trials (order counterbalanced across observers) containing a string of 24 written syllables, with two trials from each of three conditions: words from familiarization (same-words), syllables from familiarization grouped into new words (different-words), and different syllables than familiarization grouped into new words (different-syllables). Reading times per syllable were significantly faster for same-words vs. different-words (a 6.6% boost in reading speed). Given that syllable familiarity was equated, this provides clear evidence that auditory

SL affects reading. This difference reflects a benefit for same-words rather than a cost for different-words (which violated the learned structure), as supported by a directional test showing that same-words were also read faster than different-syllables. In sum, these results demonstrate that auditory SL can transfer to the visual domain, and reveal a new implicit benefit of SL for a core task in our everyday experience.

53.523 **The role of error-driven learning in object categorization by primates and birds**

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Research in object categorization has focused on how the primate visual system extracts shape information from images and how that system subsequently constructs object representations, with little emphasis on the way in which task demands affect the categorization process via learning. Here, we show that a simple model of associations between representations of stimulus properties and responses based on error-driven learning can account for many findings in the literature on object categorization by non-human animals. Furthermore, the model generates predictions that have been confirmed in both people and pigeons, suggesting that these learning processes are widespread across distantly related species. In Experiment 1, people and pigeons showed impaired learning to sort objects according to their basic-level category if subjects were pretrained to memorize the correct responses associated with each individual object in the task; in other words, discrimination learning 'blocked' categorization learning. Such 'blocking' is usually taken as a hallmark of error-driven associative learning. Experiment 2 used a Go/No Go task in which pigeons' responses to objects from a single category were rewarded and nonrewarded on different trials. As predicted by an error-driven learning account, generalization of responding to new objects from the category was lower when the individual training objects were informative about reward than when those individual objects were uninformative. In Experiment 3, object categorization learning was impaired when a second category of objects provided redundant information about correct responses. The same impairment was not observed when single objects provided redundant information, but the category to which they belonged was uninformative. This 'overshadowing' effect was also predicted by our model. These results indicate that, across distantly related species, prediction error is necessary for categorization learning to occur. These results thus add to a growing body of evidence implicating common mechanisms in object categorization by birds and primates.

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53.524 **The effect of familiarity and novelty on visual preference across different object and scene categories**

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With repetition, the visual preference for a synthetic human face increases, indicating a familiarity-driven effect; in contrast, the visual preference for a natural scene picture decreases, indicating a novelty-driven effect (Park, Shimojo & Shimojo, 2010). However, the reason for this dichotomy of preference for faces and natural scenes remains unknown. We addressed this question by first testing whether the familiarity-driven preference is specific to faces, and whether the novelty-driven preference is specific to natural scenes. We examined the visual preference across nine different categories: natural scene pictures, Chinese landscape paintings, face pictures, face drawings, Beijing opera facemasks, pairings of human ears, houses, apples, and 1/f noise patterns. Pairings of human ears, initially devised by P. Sinha, are images of an individual's left and right ears pasted together (Gandhi et al., 2009). They share similar skin tone, skin textures, and biological symmetry with human faces. Our results suggest a significant novelty-driven preference for natural scene pictures, replicating Park et al.'s findings. Chinese landscape paintings were unaffected by repetitions, and the difference between natural scene pictures and Chinese landscape paintings was significant. Trends for a familiarity-driven preference were found for facemasks and face drawings, similar to Park et al.'s findings with synthetic faces. However, our face pictures failed to produce the familiarity-driven preference observed by Park et al. with synthetic faces. Interestingly, a significant familiarity-driven preference was found for ear pairings, with a significant difference between ear pairings and face pictures. Of the remaining categories, houses showed trends of a novelty-driven preference, while apples and 1/f noise patterns were unaffected by repetitions.

Overall, our results suggest that the familiarity-driven visual preference is not face specific. The underlying mechanism of this preference awaits further investigations.

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53.525 Visual category learning can be accomplished either under ambiguous supervision or low feature saliency, but not under both challenges

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Visual category learning (VCL) is a cognitive process that involves identifying features shared by objects from the same category as well as features that discriminate objects from different categories even when these are not salient or when the feedback provided by supervision is ambiguous. This requires overcoming challenges both at the perceptual level and at the induction and decision-making level. To date, the interaction between these two systems has not been systematically tested. In the current study subjects learned to categorize novel 3D objects. In each VCL task objects varied along three feature dimensions, of which one was relevant for categorization and the other two were irrelevant. In one experimental condition, all visual features (both the relevant one and irrelevant ones) were highly salient and differences in each feature were easily perceived. In a second condition, all three visual features had low saliency, and consequently changes along each feature dimension were hard to detect. We show that when VCL is done with highly informative supervision in which each trial is sufficient for learning the categorization rule, people are capable of learning this rule effectively within small number of learning trials for both low and high saliency visual features. On the other hand, when each trial does not independently reveal the relevant feature, but it can be learned by accumulating evidence across trials, subjects can learn the categorization rule only when the features are highly visually salient. These data suggest that when the differences between objects of different categories are not visually salient, people fail to accumulate information across multiple learning trials, and therefore do not learn the categorization rule under ambiguous supervision. Overall, our data suggest that VCL can be done effectively either under conditions of ambiguous feedback information or poor feature saliency, but not when simultaneously facing both challenges.

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53.526 The spontaneous appeal by naïve subjects to nonaccidental properties when distinguishing among highly similar members of subspecies of birds generates the experts' birdguide.

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Whereas there is considerable evidence for the preferential employment of nonaccidental properties when distinguishing among instances of many domains of objects, some have insisted that with highly similar classes, appeal is made to metric and "configural" properties, as is evident when individuating highly similar faces. How do humans distinguish between exemplars of a highly similar subordinate class of natural entities, such as members of a subspecies of birds? Subjects without experience in bird classification were shown sets of 4-5 birds of the same family (all on the same page in the bird guide). They were to describe each bird sufficiently so that a "friend on the phone" who has those birds moving around in a cage would know which bird they are referring to. Almost all the descriptors were nonaccidental in that they could be employed to individuate a particular bird independent of pose (as long as that surface was in view) without appealing to metrics. The descriptors described either the shape of parts (e.g. "curved beak") or surface features ("e.g. black spot on belly"). To a large extent, these descriptors matched those that in the bird guide book. A subsequent test confirmed that the descriptions were indeed sufficient for naïve subjects to individuate the members of the subspecies. Even with subordinate classification of natural categories, naïve subjects seek and use nonaccidental (rather than metric) properties—the same properties used by professionals.

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53.527 Novel object learning depends on rapid eye movement sleep.

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A fundamental function of biological vision is to detect and recognize potential food items and predators from naturally cluttered backgrounds when form and coloration of target objects are similar to the background. Brady and Kersten (2003) previously showed that subjects can do this via bootstrapped learning. Sleep, specifically rapid eye movement (REM), has been shown to enhance perceptual learning. Here, we examined the role of REM sleep in object learning in ambiguous backgrounds. At 9AM and 5PM, 82 subjects were tested on an object learning task. At 1PM, subjects fitted with EEG electrodes and randomized to a quiet wake condition (QW) or nap condition with or without REM. Stimuli used are artificial, morphogenic objects that appear to be organic forms but do not resemble a familiar class of organism and are camouflaged by similar shapes. During AM training, subjects were shown three objects in cluttered backgrounds and asked to trace each object in the foreground (Trace condition). Next, subjects passively view these camouflaged objects appearing with a characteristic sound. At PM test, subjects were asked to recognize objects in the Test condition and re-trace objects in the Trace condition. REM group was significantly better than NREM and QW in recognition (Test), both QW and NREM performed just above chance. Both nap groups were significantly better than QW in the Trace condition. We found an essential role for REM sleep in learning to detect and recognize novel objects from camouflage. Rapid eye movement sleep occupies a large proportion of sleep during early development, and has been hypothesized to be related to cortical plasticity. The following results suggest that learning to recognize and segment objects that share the same form and coloration as their background requires REM sleep in adulthood and has implications for infant object learning.

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53.528 Linking perceptual experience with the functional architecture of the visual cortex

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Like other sensory cortices, the surface area of human primary visual cortex (V1) varies substantially between individuals for reasons that are unknown. Such variability is typically ignored by the vast majority of studies focusing only on commonalities in perception and visual processing. Here, we instead used functional MRI and standard retinotopic mapping procedures to show that differences in the surface area of human V1 were negatively correlated with the magnitude of a number of common visual illusions: the Ebbinghaus and Ponzo illusions, where two objects that are physically identical are made to appear different in size due to their context. We further showed that this correlation was also present for the tilt illusion, where the orientation of a central grating appears to be rotated due to the orientation of the surround. Importantly, all of these effects were specific to V1, as the surface area higher extrastriate regions did not show significant correlations. Because such illusions dissociate changes in conscious perception from differences in physical stimulation, our findings indicate not only that visual perception varies substantially across individuals, but also that the surface area of V1 is a neural correlate of differences in the contents of consciousness. Finally, we showed that V1 surface area also strongly correlated with sensitivity for orientation, but not contrast, discrimination. Taken together, our findings reveal a link between our subjective perceptual experience of the visual environment and the functional architecture of the visual cortex.

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53.529 Effect of stimulus familiarity in visual word recognition tasks

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Words are highly overlearned visual stimuli, yet words are not all used with comparable frequency in every day language, such as English written text. We tested the hypothesis that visual recognition of highly familiar

stimuli is affected by the familiarity of the stimulus. We measured recognition times of English words as a function of their frequency of occurrence in English written text. Design: Subjects performed a visual search task among six three-letter stimuli. They were instructed to identify a three-letter word among five distractors. The set of distractors was generated by merging three randomly selected letters. All six stimuli were displayed simultaneously, at a randomized location. Each stimulus was presented at a fixed eccentricity from central fixation, at a fixed contrast on a neutral homogeneous background. We presented a set of 14 target words with 20 repetitions per word, resulting in 280 trials in total. The 14 target words differed with respect to their frequency in written English text (frequency estimated according to the Corpus of Contemporary American English, COCA). Subjects received instructions to search for the target word and to identify the target word by clicking on the target using a mouse. Participants completed the experiment in 30 minutes. Six subjects completed the experiment. All participants were fluent in English and naïve with respect to the hypothesis under test. Results: We measured search times for the target word as a function of their frequency of occurrence in written English text. Error rates were negligible. Median search times varied between 1 and 2.3 sec. Three of the six subjects showed significant correlations between their search times and the target's frequency of occurrence in written English text. More frequent words elicited faster search times. We conclude that the familiarity of the target affects search times in visual word recognition tasks.

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53.530 "They must have seen it all along" Hindsight bias in interpersonal cognition via visual priming

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Hindsight bias, or the curse of knowledge, refers to our tendency to view outcomes as being obvious, predictable and/or inevitable once they have occurred. Such biases emerge in settings ranging from sporting event recaps to medical malpractice cases. Hindsight bias has been studied mainly in high-level cognitive tasks such as assessing the predictability of historical events. We explore hindsight in the visual domain, where an analogous process occurs with priming: A noisy image seems perceptually clearer if the observer has been previously presented with a clear version of the image.

This experiment concerned the ability of subjects, "Principals", to estimate the performance level of a separate group of "Agents" whose task was to detect humans in blurred images. Principals and Agents saw the same stimuli, except that Principals were primed by viewing fully clear versions of the images. We found that the Principals displayed hindsight bias, greatly overestimating the performance of the agents. Moreover, the measured levels of hindsight bias plotted across true task difficulty are remarkably similar to those seen in high-level cognition, such as hindsight on the predictability of historical events.

One hypothesized mechanism for hindsight bias is that, while Agents must evaluate information relevant to all possible outcomes, Principals focus on the information that relates to their known outcome. In typical hindsight tasks, this is difficult to test because of limited access to subjects' internal thoughts and considerations. In our case, we were able to track subjects' considerations via eye-tracking. We measured the correlation between Principal and Agent eye positions, and regressed the levels of hindsight against these correlations. We found a significant positive relationship - the more the Principal and Agent diverged, the more the Principal overestimated the Agents' performance.

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53.531 Action Alters Object Identification: Wielding a Gun Creates a Bias to See Guns

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Attentional states, beliefs, expectations, and emotions influence an observer's ability to detect and categorize objects. In light of recent work in action-specific perception, however, there is another, unexplored, factor that may be critical in object identification: The action choices available to the perceiver. According to the action-specific account of perception, people perceive their environment in terms of their ability to perform an action.

Individual variability in body type, performance skill, and intended behavior all scale optical information when making perceptual judgments. To determine if this scaling extends to the identification of objects, we asked whether people holding guns adopt different criteria to classify objects as threatening or nonthreatening. Across multiple experiments, participants determined whether another person was holding a gun or a neutral object such as a wallet. Critically, the participant did this while holding either a gun or a ball. Participants were instructed to raise their held object, as quickly and accurately as possible, if they detected a gun, and to lower their held object in the absence of such a threat. Signal detection analyses showed that holding a gun biased observers to report "gun present" while holding a ball biased observers to report "gun absent." Thus, by virtue of affording a perceiver the opportunity to use a gun, he or she is more likely to classify objects in a scene as threats and, as a result, to engage in threat-induced behavior (in this case raising a firearm to shoot). These findings provide empirical credence to the familiar saying that when you hold a hammer everything looks like a nail. But, in this case, when you hold a gun, everything looks like a target. In addition to theoretical implications for event perception, object identification, and decision making, these findings have practical implications for law enforcement and public safety.

53.532 The effect of holistic versus analytic processing on gender difference in memory

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Object-location memory has been considered one of the few spatial abilities in which women outperform men (Honda & Nihei, 2009). For object-location memory is a complex multi-component process consisting of identifying the object, remembering the location and binding of them (Postma, Jager, Kessels, Koppeschaar, & Van Honk, 2004), which component causes the female advantage remains unknown. The question explored in this study was whether the difference between men and women shown in object-location memory could be arisen from the difference in encoding process. Specifically, holistic versus analytic processing that Nisbett and Miyamoto (2005) suggested as cultural effect on perception might explain the gender difference in object-location memory. To test this hypothesis, we carried out an experiment composed of learning - retention - test phases. In the incidental learning phase, participants saw composite pictures made up of figure and ground, thinking the familiarity of the scenes. After five-minute-retention phase, they did sudden memory tests. In the test phase, participants judged figure and ground separately as seen or not seen for the four kinds of picture sets: the exactly same as learned, the same figure and changed ground, the changed figure and same ground, and the changed figure and ground. The analysis of the results showed that participants were overall more sensitive to ground than figure irrespective of gender. It was consistent with the previous findings that East Asians were more sensitive to contextual changes than to focal object changes (Masuda & Nisbett, 2006). In addition, we also found that women's sensitivity to figure is significantly higher than that of men's, whereas they did not show statistically significant difference in sensitivity to ground. It implied that female advantage in object-location memory could be probable due to higher sensitivity to figure, namely analytic processing.

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53.533 De Buijn cycles for neural decoding

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Stimulus ordering is critical in studies of "carry-over effects": the impact of stimulus history and context upon neural response. All studies of neural adaptation are measures of carry-over effects, as are studies of anticipation, priming, contrast, and temporal non-linearity. These effects are measured efficiently and without bias only in the setting of counter-balanced stimulus sequences.

We introduce de Buijn cycles, a class of combinatorial objects, as the ideal source of pseudo-random stimulus sequences with arbitrary levels of counter-balance. Neuro-vascular imaging studies (such as BOLD fMRI) have an additional requirement imposed by the filtering and noise properties of the method: only some temporal frequencies of neural modulation are detectable. Extant methods of generating counter-balanced stimulus sequences yield neural modulations that are weakly (or not at all) detected by BOLD fMRI. We have developed a novel "path-guided" approach for the genera-

tion of de Bruijn cycles which produces sequences with markedly improved detection power for neuro-vascular imaging techniques. These sequences may be used to study stimulus context and history effects in a manner not previously possible.

We will describe a method for creation of these sequences and provide several worked examples of possible BOLD fMRI experiments. One example study is of neural adaptation to transitions between 16 stimuli drawn from a two-dimensional stimulus space. We derive an order of stimulus presentation that provides a 2-fold improvement of statistical power with second-level counterbalance, and a 10-fold improvement with third-level counterbalance. We will demonstrate the applicability of these types of designs to a broad array of neuroscience experiments, including those that make use of multi-voxel pattern analysis.

Spatial vision: Summary statistics

Tuesday, May 10, 8:15 am - 12:15 pm

Vista Ballroom, Poster Boards 534 - 541

53.534 The Rapid Extraction of Statistical Properties in Visual Search

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Duncan and Humphreys (1989) proposed that search efficiency decreases as target-distractor similarity increases. The items that best resemble the target are grouped together, whereas the items that do not resemble the target are grouped together, and discarded. Search is then based only on the items that received the most activation. According to Ariely (2001) perceptual averaging (i.e., the ability of observers to represent sets of similar objects by their overall statistical properties, rather than their individual properties) could possibly facilitate this grouping process (see also Rosenholtz, 1999). In the present set of studies we used a series of conjunction search tasks to demonstrate that size averaging operates to improve the efficiency of search among items varying in size when size is both a) relevant to the search task (localize a target circle, defined by a color/size conjunction, Experiments 1 and 2) and b) irrelevant to the search task (localize a target line, defined by a color/orientation conjunction, Experiment 3 and 4). Results showed that search for a target was slower when target size corresponded to the average size of the distractors than when it did not (Experiment 1); that search was slower when target size corresponded to the average size of distractors appearing in the same color as the target than when it did not (Experiment 2); and that search was less efficient when target size corresponded to the average size of distractors appearing in the same color as the target than when it did not, even though target size was not a relevant search criterion (Experiments 3 and 4). These results emphasize the role of perceptual averaging in visual search among items varying in size, suggesting that targets are located first by segregating items into perceptual groups (by color) and then by isolating possible targets from distractors by size.

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53.535 Psychophysical evidence for a common metric underlying number and density discrimination

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While observers are adept at judging the density of features present in a visual texture it has recently been proposed that they also have an independent sense of visual number. Here we explore the notion that these abilities tap into a common mechanism. To this end we examined the effects of manipulating the size, contrast and contrast-polarity of individual elements as well as the attentional resources available to the observer. Our prediction is that if a common mechanism underlies density and number judgements then similar effects should be found on discrimination of density and number. Observers (n=5) always made a 2-IFC discrimination based on the relative numerosity/density of two patches (presented either side of fixation) containing 16-1024 Gaussian blobs. By mismatching patch-size between the two intervals observers were forced to make their judgements based either on density or number. We report that larger stimulus-patches biased perception towards greater density and numerosity, an effect that was amplified under conditions of increased uncertainty about element-size. Mis-

matching element-size between patches led to large observer biases and elevated thresholds for both density and number discriminations, whilst performance was relatively unaffected by manipulations of element contrast or polarity. Finally, under conditions of increasing attentional load thresholds were similarly elevated for both number and density tasks. Thus, all experimental manipulations had near-identical effects on density and number judgements, supporting the notion of a common underlying metric. Many of our results – in particular the devastating effect of manipulating element-size – are consistent with our model of number/density estimation based not on a representation of individual “objects” but simply on the relative responses of high and low spatial frequency filters.

Acknowledgement: Funded by the Wellcome Trust

53.536 Density discriminations are less precise than size discriminations, but are not more noisy

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We adapted Ross & Burr (JOV 2010) to examine the relative precision of dot density and area discriminations. A reference contained 60 dots randomly distributed within a circle of fixed area. The number of dots in the test stimulus was varied over trials by an adaptive method (Watt & Andrew's APE). In ‘Density’ blocks the area of the test was kept the same as the reference. In ‘Size’ blocks, the density of the test was held constant and size varied. In ‘Mixed’ trials the two conditions were randomly interleaved and observers indicated whether the stimulus was denser, less dense, larger or smaller. RESULTS: (a) Weber fractions for density were higher than for size when expressed as changes in dot number. This result is not consistent with observers discriminating density/area through changes in number (b) Thresholds were also higher for density in the Mixed blocks (c) On trials when the test and reference had equal dot numbers, observers chose the ‘size’ and ‘density’ responses equally often. DISCUSSION We fit the data from all conditions together with a MAX model in which observers choose the largest deviation of 4 signals from zero, with 2 parameters representing noise for the two tasks. The model fails because it predicts that observers will choose the (noisier) density option more often on mixed trials when signal strength is low. A much better model is that the transduced density signal has a lower signal/noise ratio than the area signal. Our findings do not rule out the possibility that there is a numerosity signal, but if so, it has an even lower precision than density.

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53.537 A summary-statistic model of the visual periphery predicts the difficulty of visual curve tracing.

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Observers can quickly and accurately report if two dots lie on the same contour, however task difficulty can vary substantially with the curvature and density of contours. Judging such spatial relationships is thought to require “visual routines” (Ullman, 1984), which are basic operations for marking items, diffusing activation within a region, or tracing a contour. Performance across a range of stimulus conditions has previously been modeled as an explicit tracing process in which a “zoom lens” rapidly moves along the contour between target dots. Though this model accounts well for human performance, its relationship to the human visual system is unclear. We propose that curve-tracing difficulty does not follow directly from constraints upon a high-level tracing “routine,” but may instead hinge on low-level information that is lost in peripheral vision (Balas et al., JOV 2009). Our model assumes that the visual system computes texture-like summary statistics in the periphery and estimates appearance from this lossy code. We assume that texture features are measured within peripheral pooling regions that scale with eccentricity in accordance with Bouma's Law. We first replicated previously-reported behavioral effects of contour density and curvature on “same-contour” tasks in human observers. We extend our previous methodology (Rosenholtz et al. VSS Symposium, 2010) to generate images that match the experimental stimuli in terms of local texture statistics. These images reflect what the stimuli “look like” to our model. We calculated d' values for the model by observing how often the synthesized images preserved the original spatial relationship between the target dots. Our model's d' scores capture the behavioral effects exhibited by human

subjects, suggesting that performance in this task may be explicable by the lossy encoding of peripheral vision and consequent ambiguities imposed upon appearance.

Acknowledgement: Qualcomm

53.538 The effect of viewing eccentricity on visual enumeration

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Visual acuity and contrast sensitivity progressively diminish with increasing viewing eccentricity. Here we evaluated how visual enumeration is affected by visual eccentricity, and whether subitizing capacity, the accurate enumeration of a small number (<3-4) of items, decreases with more eccentric viewing. Participants enumerated gratings (0-9) presented for 50 ms along an imaginary circle at eccentricities of 2.25, 4.5, 6.75, 9 and 11.25 deg. We found that enumeration accuracies (proportion correct) decreased with increasing eccentricity. However, the subitizing capacity was constant at 3 items across all eccentricities except at 11.25 deg, where subitizing capacity was decreased to 2 items. We also analyzed the distribution of the responses. Mean responses as a function of number deviated from the unit slope as the gratings were presented at larger eccentricities. The coefficient of variation, a normalized metric of enumeration precision defined as the standard deviation divided by the mean (Palomares & Egeth, 2010), plotted against number of patches resulted in log-log slopes ranging from -.39 to -.65. Our results show that increasing viewing eccentricity makes enumeration less accurate, but that the critical features of enumeration functions are generally resistant to the effects of viewing eccentricity.

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53.539 Size discrimination: On the relationship between statistical averaging and crowding

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We evaluated the relationship between two indices of visuospatial integration: the susceptibility to visual crowding (Pelli, Palomares, & Majaj, 2004) and the encoding of summary statistics of visual arrays (Ariely, 2001). While visual crowding is the disruption of an element's identifiability when embedded in an array of multiple elements, statistical averaging of visual arrays is the accurate identification of the global statistical average relative to the identification of individual members. It has been proposed that crowding of a target occurs due to compulsory averaging of the target with its neighbors (Balas, Nakano, Rosenholtz, 2009; Dakin, Bess, Cass, & Watt, 2009; Whitney, 2009). In the current study, we presented three squares along an imaginary circle (5 deg viewing eccentricity) and asked observers to perform a crowding and an averaging task as a function of inter-element distance. In the crowding task, we asked observers to identify the size of the central square (i.e. target) in between the two flanking squares (i.e. distractors). In the statistical averaging task, we asked observers to identify the average size of all the squares. Results show that accuracy for identifying the target improves with increasing inter-element distance in the crowding task, but accuracies for identifying the average size were unaffected by inter-element distance. However, additional analysis shows a reliable effect of choice type (i.e. target vs. average size; target vs. distractor), suggesting that "implicit" averaging contributes to the loss of identification accuracy in visual crowding. These results suggest that explicit statistical averaging of size does not share distance-dependent mechanisms that mediate visual crowding.

53.540 Perceptual averaging by eye and ear: Computing visual and auditory summary statistics from multimodal stimuli

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Beyond perceiving the features of individual objects, we also have the intriguing ability to efficiently perceive average values of collections of objects across various dimensions — e.g. the average size of a sequence of discs presented one at a time. Over what features can perceptual averaging occur? Work to date has been limited to visual properties, but perceptual experience is intrinsically multimodal. To find out how perceptual averaging operates in multimodal environments, we explored three questions. First, we asked how well observers can average an auditory feature over time: the changing pitch of a single tone. Not only was auditory averaging robust, but it was more efficient than visual averaging (of the changing size of a disc over time), equating the magnitudes of the changes. Second,

we asked how averaging in each modality was influenced by concomitant congruent vs. incongruent changes in the other (task-irrelevant) modality, again combining sizes and pitches. Here we observed a clear and intriguing dissociation. Incongruent visual information hindered auditory averaging, as might be predicted from a simple model of generalized perceptual magnitudes. However, congruent auditory information hindered visual averaging — perhaps due to a Doppler effect induced by the perception of a disc moving in depth. When modalities are readily separable, you may be able to attend to any modality you choose; but when modalities are readily bound into a cohesive whole, vision may dominate. Finally, we asked about the ability to average both pitch and size simultaneously, and we found very little cost for averaging in either modality when subjects did not know until the end of a trial which average they had to report. These results collectively illustrate that perceptual averaging can span different sensory modalities, and they illustrate how vision and audition can both cooperate and compete for resources.

Acknowledgement: NSF Graduate Research Fellowship

53.541 Distractors, sequential presentation have no effect on simultaneous enumeration of multiple sets

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Recently, Halberda et al. (2006, Psychol. Sci.) showed that with displays containing multiple spatially overlapping sets presented simultaneously, observers can successfully enumerate three such sets (two subsets plus the superset of all items). Here we aim to answer two questions related to this observation. First, we asked whether the selection of sets includes everything on a display, or whether it can be restricted to only the task relevant sets. We introduced a set of grey distracter dots to every display — effectively adding another colored set — and instructed observers to ignore them. We found that performance did not decrease with the addition of these grey dots, even on the enumeration of the superset which required the exclusion of all the grey dots. Second, we asked whether the three set limit is a result of the simultaneous presentation method used and whether more sets may be enumerated when sets are presented sequentially one at a time. We found no change in observers' enumeration capacity in sequential displays compared to that obtained from simultaneous displays. This indicates that not only does the presentation method have no influence on the enumeration of multiple sets, but also that the superset can be summed across multiple sequential presentation.

Spatial vision: Crowding and eccentricity

Tuesday, May 10, 8:15 am - 12:15 pm

Vista Ballroom, Poster Boards 542 - 555

53.542 The extent of the vertical meridian asymmetry

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Goals: How does visual perception vary as a function of location? Performance decreases as eccentricity increases, but performance at isoeccentric locations is not homogenous. Performance is better along the horizontal meridian than along the vertical meridian. Along the vertical meridian, performance is better along the lower than the upper portion. This pattern of asymmetries is referred to as a performance field (e.g. Carrasco, Talgar, & Cameron, 2001). Some have reported a general upper versus lower visual field asymmetry, which is considered to reflect the ecological constraints of the environment (e.g., Previc, 1990). Here, we investigate the angular extent of the vertical meridian asymmetry.

Methods: In two experiments, observers performed an orientation discrimination task on Gabor stimuli of varying contrast at a series of isoeccentric locations. Interleaved adaptive staircases controlled stimulus contrast, enabling the measurement of sensitivity at each location. In Experiment 1, we measured sensitivity at sixteen equally spaced isoeccentric locations. In Experiment 2, we narrowed this range to focus on the locations within $\pm 45^\circ$ of the upper and lower vertical meridian.

Results: Consistent with previous studies, we found that contrast sensitivity is lowest along the upper vertical meridian, higher along the lower vertical meridian, and highest along the horizontal meridian. The upper versus lower asymmetry is most pronounced along the vertical meridian,

but it does extend beyond the vertical meridian. The asymmetry gradually decreases as angular distance from the vertical meridian increases, disappearing by $\pm 45^\circ$. This behavioral asymmetry mirrors the asymmetries of the LGN (e.g., Connolly and van Essen, 1984), suggesting that anatomical constraints underlie behavioral performance fields. These data do not support a general upper versus lower visual field asymmetry related to ecological constraints.

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53.543 Contour interaction under monocular and dichoptic viewing conditions for luminance-modulated and contrast-modulated Cs

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Resolution acuity is degraded by the presence of flanking bars. This contour interaction is observed under monocular and dichoptic viewing conditions, pointing to its cortical origin (Flom et al, 1963). The exact locus of the interaction remains unclear but areas beyond V1 have been suggested (review by Levi, 2008). The peak of contour interaction for contrast-modulated (CM) stimuli is higher than that observed for luminance-modulated (LM) stimuli under monocular viewing conditions (Hairiol et al, VSS2010). CM stimuli are thought to be processed at a higher, more binocular cortical region than LM stimuli, and binocular interactions at the level of detection are different for the two types of stimuli (e.g. Waugh et al, VSS2009). We asked whether this is also true for suprathreshold stimuli and investigated contour interaction for LM and CM square-C stimuli, in monocular and dichoptic foveal viewing. In each condition, resolution thresholds were determined for a briefly presented isolated C and a C flanked by bars placed from abutting to one optotype width away from the target. The target was presented to the non-dominant eye. With monocular viewing, we again found that the peak contour interaction was greater for CM than for LM stimuli (by ~ 0.1 logMAR). Under dichoptic viewing conditions, contour interaction for LM stimuli was on average greater (by ~ 0.05 - 0.1 logMAR) and more extensive than in monocular viewing, but this change was not observed for CM stimuli. The lack of enhancement of contour interaction for CM stimuli under dichoptic conditions (where neural combination of target and flankers is required) suggests that these stimuli may be processed at the (binocular) locus of contour interaction. The differential effect of viewing conditions on the interaction for LM stimuli supports the notion that the processing of these stimuli takes place at a lower cortical level than that of CM stimuli.

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53.544 Visual Boundaries Influence the Direction of Biases in Peripheral Localization

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Previous studies on localization of stimuli in peripheral vision have predominantly reported underestimation of the distance of targets from fixation (foveal bias). However, a few studies have also found peripheral biases, and these studies have all employed manual responses. Here we show that peripheral biases in localization are also evident with verbal responses. Experiments were conducted using a Goldmann Perimeter with target dots presented at 10° intervals along the cardinal axes. Participants either marked perceived location of targets along a line on a sheet of paper that represented their visual field extent along each axis, or they made verbal magnitude estimates between 0 (point of fixation) and 100 (perceived edge of visual field). Both tasks showed peripheral biases when participants estimated target locations relative to their perceived visual field extent. However, the magnitude of responses as a function of eccentricity only deviated from linearity for those axes that are not restricted by an external visual boundary (i.e., the brow and the nose). The importance of the external visual boundary is supported by comparing scaling of localization estimates along the left axis (horizontal meridian) in binocular or monocular (right eye) viewing conditions. Scaling was linear for the monocular condition (where the left axis represents the nasal visual field) and deviated from linearity, with a significant peripheral bias, in the binocular viewing condition. This result cannot be accounted for by localization biases that are specific to the nasal visual field, because when verbal judgments were

made relative to the edge of a physical aperture, all axes showed a linear scaling of responses, significant foveal biases, and no differences in scaling along the left axis between monocular and binocular conditions. We conclude that the type of boundaries used to define a space influences biases in peripheral localization that are independent of response type.

53.545 ASSESSMENT OF DAMAGED AND INTACT VISUAL FIELDS WITH A NEW KIND OF PERIMETER

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An inexpensive method to characterize visual field defects due to neural damages was developed. Stimuli are presented on a large computer screen at a number of pre-selected locations in a randomized order. The sensitivities at these locations are measured independently with a number of simultaneously running threshold estimation algorithms. The stimuli are M-scaled, which means their size is increased with increasing eccentricity in inverse proportion to the cortical magnification factor. The purpose of M-scaling was to make the stimulus representation homogenous on the primary visual cortex so that the sensitivity values measured at different visual field locations would be comparable. The task was either the detection of flickering or static disks or recognition of flickering or static letters. Two groups of subject participated in the experiments - normal sighted and hemianopic patients. There was a general tendency that sensitivities increased toward peripheral vision to some extent in the intact visual field. This effect was slightly more pronounced for letter recognition than disk detection. In disk detection flicker more than doubled the sensitivity in comparison to static stimulus detection. However, in letter recognition flicker only had a negligible effect. In the hemianopic visual field, the sensitivity was in general considerably lower than in the intact visual field. However, completely blind spots were rare, and all patients exhibited residual vision of the defected visual field. Hemianopia produced a reduction of relative sensitivity that was not significantly dependent of stimulus type. The results also showed that the new method is sensitive to cortical visual field defects and it is reasonably fast.

53.546 Letter-in-chaff: a response classification method for studying letter identification

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First-order classification image techniques can reveal the perceptual templates used by an observer to perform a detection or discrimination task. Although the technique has been extended to infer higher-order sub-template features, the typical method of using pixelated noise poses problems of tractability for higher-order analyses. Here we propose a simplified stimulus with the aim of recovering the features involved in letter identification and crowding.

We created a 16-segment display, similar to a digital clock, that can produce letters. In our experiment, one of ten possible target letters was presented per trial in a central display embedded within a larger array of replicated 16-segment grids. I.i.d. Gaussian contrast noise was added to all segments. Observers identified the target and also indicated the position they thought the target appeared. Contrast of the target was controlled by a modified QUEST procedure to maintain performance at 50% correct. We collected 10,000 trials of data for 2 observers in a foveal condition and 2 observers at 10 deg eccentricity.

First-order classification images based on contrast noise were vivid in both fovea and periphery conditions. Observers' estimations of target position were accurate at the fovea; in the periphery, they were elongated towards fixation. Second-order features defined as noise correlations between unique pairings of segments that could occur within one letter width and height often did not correspond to salient sub-template features of the first-order images. Instead, they revealed an interaction between the noise and signal presented in those error trials. Features used to identify a letter are not necessarily the parts of the letter - they can be the parts of a distractor, which must be perceptually excluded.

Our letter-in-chaff stimulus offers a tractable construction to study the sub-template features involved in letter identification, and potentially uncover the rich feature-feature interactions in peripheral crowding.

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53.547 Effects of imposed Gaussian blur on contour interaction for luminance-modulated and contrast-modulated noisy Cs

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Contour interaction for visual acuity is greater for contrast-modulated letters than for luminance-modulated letters and appears to be more robust to the effects of dioptric blur (Hairol et al; Waugh et al, VSS2010). As dioptric blur can be complicated, we investigated the effects of controlled imposed image blur on contour interaction for contrast-modulated (CM) and luminance-modulated (LM) C stimuli. Stimuli were constructed from dynamic binary noise, added or multiplied to a square-wave profile. Noise was either unscaled, subtending a constant angular size for all Cs, or scaled to have ~15 noise checks per C. We measured acuity for square Cs, with and without four flanking bars separated by 0-2 letter widths under different levels of image blur. Blur was created by filtering the image with low-pass Gaussians (sds of 32-0.5 c/deg). Acuity thresholds (logMAR) were obtained using a method of constant stimuli and 4AFC paradigm. Visual acuity thresholds for CM Cs were always higher than for LM Cs by 0.3-0.4 logMAR. This difference was magnified when bars were placed next to (0.4-0.6 logMAR) or close to (0.4-0.5 logMAR) the target C. Across blur levels the amplitudes and the extents (in barwidths) of contour interaction were greater for CM than for LM Cs, particularly for unscaled noise. The initial rate of improvement in visual acuity (MAR) with decreasing blur (increasing Gaussian sd) for crowded and uncrowded Cs, was similar for LM and CM Cs (power function exponent of ~-0.9), although slightly flatter for CM Cs constructed with scaled noise. As with dioptric blur, CM stimuli are more susceptible to the effects of contour interaction than LM stimuli with imposed image blur, especially for unscaled background noise. Differences reduce for scaled noise, suggesting that the effects of blur on carrier noise contribute in part, to the overall visual acuity response.

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53.548 The Neural Correlates of Crowding-Induced Changes in Appearance

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Crowding is the breakdown in object recognition that occurs in cluttered visual environments. Despite being the principal restriction on perception in the peripheral visual field, its cortical locus remains unclear. Greenwood et al. (2010, *Current Biology*, 20(6):496-501) recently demonstrated that crowding changes the appearance of objects, such that a crowded patch of noise, surrounded by oriented Gabor flankers, becomes perceptually oriented to match the flankers. Under such conditions, substituting the noise patch for an oriented Gabor (identical to the flankers) goes unnoticed. Here, we combined an event-related fMRI adaptation paradigm with a change-detection task to determine the neural correlates of the crowded percept. Observers monocularly viewed a peripheral noise patch surrounded by four Gabors. After 500ms the noise either remained unchanged (no-change), or was substituted for a Gabor that either matched (same-change) or was orthogonal to the flankers (different-change). Observers rarely detected the substitution of a perceptually matched Gabor (same-change), but nearly always detected the substitution of an orthogonal Gabor (different-change). We predicted that cortical areas reflecting the crowded percept would show repetition-suppression on trials where the noise was substituted for a perceptually matched Gabor (i.e. same-change condition but no-change perceived), and the fMRI response would be indistinguishable from that for the no-change trials. In contrast, we predicted release from adaptation when the noise was substituted for a perceptually orthogonal Gabor (different-change). This predicted pattern of activation was observed in early retinotopic cortex, weak in V1 compared to later visual areas (V2-V4). Our findings suggest that the perceptual consequences of crowding are manifest in early visual areas, in particular those upstream from V1.

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53.549 Invisible fearful face induced by crowding can capture spatial attention

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It is difficult to detect and recognize a peripheral face in a crowd compared to when the face is presented isolated, a phenomenon known as crowding. A strong crowding effect can even render a face completely invisible, which is perceived to be indistinguishable from its scrambled version. It is not known to what extent the invisible face can be processed by the visual system. Here, we studied whether invisible emotional (fearful and happy) and neutral faces induced by crowding can influence spatial attention. A Posner cueing paradigm was adopted to measure the spatial cueing effect of invisible faces on an orientation discrimination task. A fearful, happy or neutral face was presented briefly in either the lower left or the lower right quadrant. Meanwhile, a scrambled neutral face was presented in the contralateral position. Both of them were flanked by inverted neutral faces, which rendered the face invisible as confirmed by a face detection task. Then a gabor patch was randomly presented at the position of either the face or the scrambled face. Subjects had to indicate the orientation of the gabor (clockwise or counterclockwise tilted). We found the attentional cueing effect only with fearful faces. That is, subjects' performance was better when the gabor was presented at the position of a fearful face than at the position of a scrambled face. To rule out that the cueing effect was due to low-level feature differences among fearful, happy and neutral faces, we conducted two control experiments in which faces were replaced with their space-scrambled or phase-scrambled counterparts. In both experiments, no attentional cueing effect was observed for all three kinds of faces. These results demonstrate that fearful faces could survive crowding and be profoundly processed by the visual system, consequently, direct the distribution of spatial attention.

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53.550 Peripheral crowding with unlimited viewing time

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Studies of peripheral form vision are often limited to briefly presented stimuli to avoid eye movements. These duration-constrained results present a narrow perspective of peripheral form vision, and may not generalize to the visual conditions of people with central field loss. Here, we studied peripheral crowding with unlimited stimulus duration by using a gaze-contingent display. We chose crowding because it is a key limiting factor of peripheral form vision.

We measured contrast threshold elevation as a function of target-flanker spacing for identifying 26 lower case letters at 50% correct (corrected for guessing). In the FIXATION condition, subjects maintained fixation at a marker while a target letter, flanked above and below, was presented at 12 degrees eccentricity in the lower visual field for an unlimited duration. In the SCOTOMA condition an artificial central scotoma, 12 degrees in diameter, constrained target eccentricity.

Wallace and Tjan (2010 VSS), using the same stimuli with 250 ms duration, reported a spatial extent of crowding of between 3-4 degrees at 10 degrees eccentricity and a contrast threshold elevation of 10. The median stimulus duration (and response time) in the current study was 900 ms. The spatial extent of crowding was 1.5-2.3 degrees across subjects and conditions, which is half of the short-duration experiment after adjustment for the eccentricity difference. Threshold elevation remained unchanged. Compared to the FIXATION condition, the SCOTOMA condition was 80 ms longer in presentation duration, but slightly smaller in spatial extent of crowding.

Our results show that peripheral form vision is effortful: the preferred stimulus duration is many times the duration in a typical peripheral-vision experiment (900 ms vs. 100-200 ms). While duration significantly reduced the spatial extent of crowding, the effect of crowding (e.g. threshold elevation) remains the same. Theories of peripheral form vision should account for this dynamic aspect of crowding.

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53.551 Can positional averaging explain crowded letter confusions?Daniel Coates¹(daniel.coates@berkeley.edu), Jean-Baptiste Bernard¹, Susana Chung¹; ¹Vision Science Graduate Program, University of California, Berkeley

Crowding, the failure to correctly identify objects in the periphery when surrounded by nearby distracting forms, continues to be an effective phenomenon for studying general object recognition. Recent studies with simple stimuli have shown convincingly that crowding reveals an averaging process, at least for continuously-varying stimuli. We asked whether crowded letter identification, a multi-dimensional categorical operation, can expose a pattern of responses interpretable as positional averaging. To directly probe this question, we generated symbols composed of a circle and a vertical line, combined to form shapes varying on a spectrum between 'b' and 'd' or 'p' and 'q'. Our targets consisted of one lower-case Arial letter from the set 'bdpqol' in a central position flanked by symbols on either side of the letter. Observers were asked to identify only the central letter, and were informed of the six possible choices. The stimuli were presented at 10 degrees below fixation for 150 ms. When an error occurred (33% of trials), the mistakes were essentially due to the vertical line features. The circle feature rarely migrated from the flankers to the target and was seldom undetectable in a target letter. Instead, the vertical line either migrated from a flanker into the target or shifted its position within the target. Consistent with the positional averaging prediction, the relative position of the vertical line in the flankers biased the reported letter. Observers were twice as likely to respond with an erroneous letter whose ascender/descender corresponded with the average of the relative line positions of the flankers. Our results are also consistent with the "faulty feature migration" explanation of crowding, which states that features from sufficiently similar flankers are inappropriately integrated into the target. Our new contribution is that letter features migrate in a fashion that respects the internal spatial configuration of the flanking forms.

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53.552 Response bias contributes to visual field anisotropies for crowding in natural scenesLuis Andres Lesmes¹(luis.lesmes@schepens.harvard.edu), Thomas S.A. Wallis¹, Peter Bex¹; ¹Schepens Eye Research Institute, Harvard Medical School

Purpose. Visual discrimination in the periphery is limited by crowding, and previous research suggests that crowding effects vary across the visual field. Specifically, the upper visual field is more crowded (less sensitive) than the lower visual field and the vertical meridian is more crowded than the horizontal. To distinguish the contributions of perceptual and decision factors to crowding in natural images, we applied Luce's Choice Model to describe sensitivity and response bias across the visual periphery. Method. In a spatial 4AFC task, observers viewed static natural images and identified the location of a target patch of "dead leaves" (overlaid ellipses of random size, orientation and aspect ratio), superimposed at one of four directions relative to fixation (N, S, E or W) and one of three eccentricities (2, 4 or 8°, varied across blocks). A staircase converging on the level of 50% correct controlled the size of the target patch. The level of crowding at each location was assessed by the patch size corresponding to threshold performance. Results. A conventional analysis that ignored bias effects yielded several characteristic crowding asymmetries: for two of three observers, the upper visual field was less sensitive than the lower, and the vertical meridians were less sensitive than the horizontal. When performance was considered as a function of both sensitivity and bias, sensitivity decreased linearly with eccentricity (a crowding signature), but only the vertical-horizontal asymmetry remained consistent. The previously inferred anisotropy was thus better described as a difference in response bias. That response bias changed across directions but not eccentricity suggests possible contribution of a motor bias. Conclusion. These results highlight the importance of considering the dual contributions of sensitivity and response bias to performance accuracy in multiple alternative forced-choice paradigms. Failure to account for response bias can lead to erroneous conclusions concerning anisotropic sensitivities.

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53.553 Effects of target-flanker grouping in crowding inside and outside the critical spacingBilge Sayim¹(bilge.sayim@parisdescartes.fr), Patrick Cavanagh^{1,2}; ¹Centre Attention & Vision, Laboratoire Psychologie de la Perception, Université Paris Descartes, ²Department of Psychology, Harvard University

Peripheral target perception is impaired by close-by flankers, an interference that is called crowding. For example, discriminating the orientation of a rotated letter T is compromised when it is flanked by other Ts. Besides target-flanker distance, an important factor that determines crowding is the degree to which target and flankers group: The more the target groups with the flankers, the stronger the crowding (e.g., Saarela, Sayim, Westheimer, & Herzog, 2009). Here, we investigate whether target-flanker grouping can also alleviate crowding. A target letter T had two sets of flankers making a cross shape with the target in the center. The first set were "crowding-flankers" with two Ts of varying orientations placed to the left and right side of the target. The second set were "grouping-flankers" both with the same orientation placed above and below the target. In the grouped condition, the target had the same orientation as the grouping-flankers whereas in the ungrouped condition, the target had a different orientation from the grouping-flankers. Observers reported the orientation of the target. The proportion correct was higher in the grouped compared to the ungrouped condition indicating that grouping-flankers counteract crowding. This effect was observed even when the grouping-flankers were presented outside the critical spacing for crowding (too far from the target to yield crowding). Further experiments showed that in the grouped condition, both hits and false alarms increased showing a bias to reporting the target as having the same orientation as the grouping flankers. We suggest that this bias reflects perceptual assimilation of the target with the grouped items.

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53.554 Crowding with invisible flankersKilho Shin¹(kilhoshi@usc.edu), Bosco S. Tjan^{1,2}; ¹Department of Psychology, University of Southern California, ²Neuroscience Graduate Program, University of Southern California

Crowding is a key limiting factor of form vision in the periphery. The neural origin of crowding is not known. Here we tried to establish an upper bound on the earliest neural stage of crowding by rendering the flankers invisible with interocular suppression.

We presented to the non-dominant eye of a subject a target Gabor at 5-degree eccentricity surrounded by 1-4 Gabor flankers on four sides in Experiment 1 and zero, 1, or 4 flankers in Experiment 2. We presented to the dominant eye four 100%-contrast dynamic concentric checkerboards (suppressors) at the same positions of the flankers. Subjects performed two tasks. The first task was to discriminate (clockwise vs. counter-clockwise) the orientation of the target Gabor relative to the reference direction of 45 degrees. The second task was to indicate the number of Gabors seen. A fixation and a pair of nonius lines were used to achieve fusion lock. Initiated by the subject, stimuli for both eyes were presented simultaneously for 100ms. The contrast of the Gabors was 60% in Experiment 1 and 50% in Experiment 2.

Since there were always four suppressors, when the flankers were fully suppressed (82% of the trials in Experiment 1, 100% in Experiment 2), the subjective percept of the stimulus was unaffected by the actual number of flankers. Nevertheless, we found that for both experiments, discrimination accuracy decreased as the number of the flankers increased for the trials when the flankers were invisible. For the remaining 18% of the trials in Experiment 1, during which subjects reported seeing one or more flankers, the reported number of flankers accounted for no additional variance in discrimination accuracy. These results suggest that crowding starts at a visual-processing stage prior to interocular suppression, which is likely to be early, such as in V1.

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53.555 SPATIAL FREQUENCY AND SIMILARITY MODULATE CROWDING IN LETTER IDENTIFICATIONSacha Zahabi¹(sacha.zahabi@umontreal.ca), Martin Arguin¹; ¹Centre de recherche en Neuropsychologie et Cognition, Département de psychologie, Université de Montréal

Visual crowding, which impairs our ability to accurately identify a target stimulus when surrounded by flankers, is ubiquitous across a wide variety of stimulus classes. Target eccentricity and target-flanker distance consti-

tute fundamental factors in crowding. Target-flanker similarity appears as another key factor based on findings obtained with non-linguistic stimuli. The present study investigated the impact of these factors in conjunction with spatial frequency (SF) content on single letter identification performance. We presented SF filtered letters to neurologically intact nondyslexic readers while manipulating target-flanker distance, target eccentricity and target-flanker similarity (metric based on published letter confusion matrices). SF filtering conditions were broadband, low-pass, high-pass and hybrid (i.e. medium SFs, known as optimal for letter recognition, removed from the stimulus). These conditions were matched on overall contrast energy. Participants were required to identify the target letter as fast and as accurately as possible. The results show that high target-flanker similarity enhances crowding, i.e. the joint effects of distance and eccentricity. This extends past findings on the impact of similarity on crowding to the visual identification of linguistic materials. Most importantly, the magnitude of the crowding effect is greatest with low-pass filtering, followed by hybrids, high-pass, and broadband, with all pairwise contrasts significant. We conclude that: 1- medium SFs provide optimal protection from crowding in letter recognition; 2- when medium SFs are absent from the stimulus, low SFs magnify crowding and high SFs protect against it, most likely through their opposite impact on the availability of distinctive feature information.

Spatial vision: Neural and psychophysical mechanisms

Tuesday, May 10, 2:30 - 4:30 pm

Talk Session, Royal Palm 1-3

Moderator: Luke Hallum

54.11, 2:30 pm

Population receptive fields in human visual cortex measured with subdural electrodes

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PURPOSE. Electrophysiological methods in animal models have been used to identify receptive field properties of neurons within retinotopic maps. More recently functional magnetic resonance imaging (fMRI) methods in human have been used to estimate population receptive fields (pRF) (Dumoulin and Wandell, 2008; Kay et al., 2008). Following Yoshor et al. (2007), we developed an efficient method of electrocorticography (ECoG) using subdural electrodes in pre-surgical clinical subjects to estimate pRFs in human visual cortex. These measures bridge human fMRI and animal electrophysiological studies.

METHODS. Two patients with implanted intracranial electrodes (2-mm surface diameter) viewed a flickering contrast pattern through a bar aperture that swept across the visual field 8 times (4 cardinal, 4 diagonal directions; 96 seconds total). The contrast pattern flickered at 7.5 Hz, creating a steady-state ECoG response with power concentrated at twice the stimulus frequency (15 Hz). For each electrode a time-series of the time-varying 15-Hz amplitude was extracted, and modeled using an isotropic 2D-Gaussian pRF.

RESULTS. The pRF model fit occipital electrodes' time-series well, explaining up to 83% of the variance. The pRF parameters were similar to those obtained from fMRI; for example, the pRF size increased with eccentricity and was larger in extrastriate regions than in electrodes near the occipital pole. The signal response latencies were estimated from the phase of the response to full-field flicker (separate runs). We observed robust position-dependent latency effects, ranging from 10-40 ms delay relative to responses near the occipital pole.

CONCLUSION. Population receptive fields can be estimated using ECoG. There is good agreement between fMRI and ECoG measures despite significant differences in their physiological bases. The ECoG data provide latency information that is unavailable in the fMRI responses. This is a valuable method for probing population-level spatiotemporal properties of receptive fields in human visual cortex.

Acknowledgement: NEI NRSA EY019244 to JW, Stanford Bio-X Graduate Student Fellowship to AR, NEI RO1-EY03164 to BW

54.12, 2:45 pm

Tomographic measurement of population receptive fields in early visual cortex

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Recently, fMRI was used to estimate visual population receptive fields (pRFs) by fitting a model shape to the measurements, permitting estimates of visual field coordinates, pRF size, and other parameters (Dumoulin & Wandell, Neuroimage 39:647, 2008). Here we demonstrate that pRFs can be directly reconstructed using a tomographic approach that requires no a priori shape assumption. Methods: We obtained fMRI images across early visual cortex using a GE 3T scanner using 2-mm voxels and a spiral acquisition. Stimulation was a thin bar (1–2.5° wide) containing a moving checkboard pattern that swept slowly (<1°/s) across a 10–20° field-of-view.

Bar motion was perpendicular to its long axis. The motion direction and bar orientation of each sweep successively rotated from 0–165° in 15° increments. Blank periods were inserted between each sweep to allow the fMRI response to subside. Assuming linearity, the fMRI time series corresponded to a projection of the pRF along the axis of the bar. The multiple sweeps thus formed a sinogram (Radon transform) that was blurred by the hemodynamic response function (HRF). Blurring was mitigated using a Wiener filter incorporating HRF waveforms measured in each scanning session. pRFs were then reconstructed from the corrected sinograms using a back-projection algorithm. Contours were created around the pRF half-maxima to estimate field coordinates and other parameters. Results: Our polar angle and eccentricity maps agree well with the previous model-based approach. pRF sizes increase with eccentricity and with visual area. Notably, individual reconstructed pRFs are complex with anisotropic (non-circular) shapes and significant suppressive surround regions. Anisotropy and suppression exhibit trends with respect to visual area and eccentricity. We present a detailed analysis of the tomographic spatial resolution that is essential to interpretation of these trends. Conclusion: Tomographic reconstruction of pRFs is a useful approach for estimating visual receptive field properties without a priori shape assumptions.

54.13, 3:00 pm

Second-order selectivity of single units in macaque primary visual cortex (V1) and V2

Luke E. Hallum¹(hallum@cns.nyu.edu), J. Anthony Movshon¹; ¹Center for Neural Science, New York University

The way humans perceive texture-defined form suggests that 2nd-order stimuli are encoded by mechanisms that receive rectified input from orientation-selective neurons like those in V1. Direct physiological evidence for 2nd-order neurons in primate visual cortex is elusive. The responses of orientation-selective neurons are often modulated by stimuli falling in the receptive field (RF) surround; a variant 2nd-order model uses inhomogeneities in the RF center and surround to create selectivity for form defined by variations in contrast and texture (Tanaka & Ohzawa, 2009). We tested this model by measuring the responses of single units in V1 and V2 of paralyzed, opiate-anaesthetized macaques. We stimulated the RF center and surround with large, contrast-modulated gratings made from a sinusoidal grating carrier modulated by a second, drifting sinusoidal grating of lower spatial frequency. The carrier was of optimal spatial frequency, orientation, and drift rate; the modulator varied across 8 drift directions and 5 or 6 spatial frequencies. We found cells in both V1 and V2 that were selective for modulator orientation and spatial frequency. We used a 2nd-order difference-of-Gaussians model to capture the spatial arrangement of the contrast-responsive center and surround regions of the RF. Cells unselective for modulator structure had classical circular centers with annular surrounds, while others – with modulator selectivity – showed diverse spatial arrangements of the RF center and surround. In many selective cells, the surround was arranged anisotropically relative to the RF center, and explained the modulator selectivity. In others, selectivity appeared to arise from an elongated RF center, in the absence of an anisotropic, suppressive surround. Selectivity for 2nd-order form may not depend on pure 2nd-order neurons, but might arise instead by selective modulation of neuronal responses to conventional 1st-order stimuli.

Acknowledgement: NIH EY04440

54.14, 3:15 pm

Failures of inference: challenges for interpreting localized fMRI measurements of visual features

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Functional MRI studies in recent years have shown that even low-resolution data reflect information represented in the neural code on a scale much smaller than the size of the voxel (decoding). However, our recent localized measurements of the fMRI response to individual Gabor elements, either alone or flanked by other Gabor patches, demonstrate unique challenges for interpretation of responses to spatial patterns. In one case the fMRI response to low-contrast Gabor patches was not reliably suppressed by

high-contrast parallel flankers, even though other studies using extended sine-wave gratings have shown that the BOLD response reflects iso-orientation surround suppression. A computational model incorporating both local/untuned and long-range/orientation-tuned inhibition resolves this discrepancy by demonstrating that the net balance of activity between neurons representing the stimulus orientation and neurons in surrounding orientation columns depends crucially on the size of the stimuli. Since fMRI reflects the responses in the entire neural population, the population-average response can obscure responses in the neural population encoding the stimulus and result in a lack of correlation between fMRI data and behavioral measurements of the responses in neurons encoding the stimulus. Contributions of local inhibitory neural activity to the BOLD response can further complicate interpretation of localized measurements. In a second experiment, we found that the relative amplitudes of the estimated fMRI response to 5% and 10% contrast Gabor patches depend on the distance of the voxel from the center of the neural representation of the stimuli. Therefore, the size of the region of interest for analysis has a significant impact on whether the fMRI response is linearly related to underlying neural activity. Taken together, these studies suggest that accurate inference of localized neural activity from fMRI data requires a detailed understanding of local neural population responses across the cortical region of interest.

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54.15, 3:30 pm

Occipital TMS facilitates and hinders visual perception via a contrast gain mechanism

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The effects of transcranial magnetic stimulation (TMS) can vary radically according to the state in which the brain is at the moment of stimulation. Two possible mechanisms by which single magnetic stimuli produce different effects according to the initial activation state of targeted neurons have been proposed: (i) TMS suppresses neural signals and (ii) TMS adds random neuronal activity. Here we explore these two hypotheses by investigating the psychophysical effects of TMS on early visual cortex under different conditions of contrast adaptation. We tested six participants in an orientation discrimination task, where neuronal activation of visual cortex before each trial was altered through adaptation either to a blank screen or to two flickering gratings. In half of the trials a single TMS pulse was delivered simultaneously with target. Adaptation decreased performance. The effect of TMS on performance depended on the state of adaptation: it increased contrast sensitivity after adaptation but reduced it in the absence of adaptation. Correspondingly, TMS had a differential effect on threshold according to adaptation: it increased thresholds without adaptation but decreased them after adaptation. Notably, TMS did not affect the asymptote in any condition. The fact that TMS changed thresholds but not asymptotes suggests that TMS acts at the input level of neuronal processing, i.e. at the synaptic level. Moreover, the finding that TMS had opposite effects on the two adaptation conditions, even at the same performance levels at threshold, contradicts the hypothesis of TMS state-dependency as a product of noise increase.

54.16, 3:45 pm

Serial dependence in visual perception

Jason Fischer¹(jtf@berkeley.edu), Jennifer Shankey¹, David Whitney¹; ¹Department of Psychology, University of California, Berkeley

Despite a noisy and ever-changing visual world, our visual experience is remarkably stable and continuous over time. One way that the visual system may promote such stability is through the introduction of serial dependence to visual perception: by biasing the current percept toward what was seen previously, the brain could compensate for variability in visual input that might otherwise disrupt perceptual continuity. Here, we tested for serial dependence in visual perception using an orientation judgment task. Subjects reported the orientations of sequentially presented supra-threshold, high contrast gratings, which were separated in time by several seconds. We found that on a given trial, a subject's perception of the grating orientation reflected not only the currently viewed stimulus, but also a sys-

tematic attraction toward the orientations of the previously viewed stimuli. This perceptual attraction extended over several trials, and displayed clear tuning to the difference in the orientations of the sequential stimuli. Furthermore, serial dependence in perceived orientation was spatially specific, occurring most strongly within a constant retinal location, somewhat less strongly across different retinal locations at the same head-centered position, and only weakly across changes in both retinal and head-centered location. Several control experiments showed that the perceptual serial dependence we report cannot be explained by known effects of priming, hysteresis, visual short-term memory, or expectation. Our results reveal a systematic influence of recent visual experiences on perception at any given moment: visual percepts, even of unambiguous stimuli, are attracted toward what was previously seen. We propose that such serial dependence helps to maintain continuity in the perception of object and scene properties in the face of a dynamic and noisy environment.

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54.17, 4:00 pm

The Intrinsic Uncertainty Observer: Explaining Detection and Localization Performance in the Visual Periphery

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Efficient performance in visual detection tasks requires excluding signals from irrelevant spatial locations. Indeed, researchers investigating visual detection and search have found that performance in a variety of tasks involving multiple potential target locations can be explained simply by the uncertainty the added locations contribute to the task. Importantly, a similar type of location uncertainty may arise within the visual system itself. Converging evidence from hyperacuity and crowding studies shows that spatial localization of features declines in peripheral vision at a rate greater than predicted by the falloff in spatial resolution. This decline in localization ability should add inherent position uncertainty to detection tasks in much the same way as adding potential target locations. The current study used a modified detection task to measure how position uncertainty changes with eccentricity. Subjects judged whether a Gabor target appeared within a cued region of a noisy display. Both the eccentricity and size of the cued region varied across blocks. On trials when subjects reported detecting the target, they used a mouse to indicate the location of the target within the cued region. This allowed measurement of localization errors as well as detection errors. The Intrinsic Uncertainty Observer, an ideal observer degraded with internal response noise and position noise, accounted for both the detection and localization performance of the subjects. The results suggest that internal position uncertainty in normal peripheral vision grows linearly with eccentricity and is independent of target contrast. Internal position uncertainty appears to be a critical factor limiting search and detection performance.

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54.18, 4:15 pm

The common perceptual metric for human discrimination of number and density

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There is considerable interest in how humans estimate the number of objects in a scene, in the context of an extensive literature on how we estimate the density of objects (i.e. how closely spaced they are). If humans have a sense of "visual number" (as has been proposed) then it should operate independently of density perception. Here we show that it does not. We had subjects discriminate the density or numerosity of two patches that were mismatched in size and show that larger patches appear both denser and (somewhat) more numerous, and that size-mismatching elevates thresholds for discriminating number and (to a lesser degree) density. We propose that density and number are both initially encoded as the ratio of responses from a pair of filters tuned to low and high spatial frequencies, but that number-estimation requires that this measure be scaled by relative stimulus-size. This model explains the rather complex dependence of observers' accuracy and precision on patch-size variation, using a simple, biologically plausible common metric for number and density. Because this model does not have any explicit representation of "objects" it predicts that

(for example) mismatching element size will drastically affect number and density discrimination, whereas contrast-mismatching will not (Tibber, Greenwood & Dakin, VSS 2011).

Acknowledgement: Funded by the Wellcome Trust

Attention: Temporal and capture

Tuesday, May 10, 2:30 - 4:30 pm

Talk Session, Royal Palm 4-5

Moderator: Steven Franconeri

54.21, 2:30 pm

Flexible visual processing of spatial relationships.

Steven Franconeri¹(franconeri@northwestern.edu), Jason Scimeca¹, Jessica Roth¹, Sarah Helseth¹, ¹Northwestern University

Many visual tasks, such as understanding a diagram, require that we process the spatial relationships between objects. There is almost no work exploring how we make these judgments in a flexible way. One hurdle is the binding problem - because our object recognition network codes object features across large regions of the visual field, there is often uncertainty about the location of any given object. Unless individual objects are isolated by selective attention, identities can become associated with the wrong object. We will demonstrate examples of this phenomenon for simple displays containing just two colors. When we process a relative spatial relation, the visual system may solve this binding problem by isolating the first object with selective attention, encoding its location into memory, selecting the second object, and then comparing its relative location. In three studies, we used an electrophysiological correlate of selection (N2pc) to demonstrate that even when dealing with just two simple objects, selection does shift sequentially between them. These shifts (1) occur despite difficult dual tasks that discourage them, (2) occur only for trials where the relation was actually perceived, and (3) do not occur for same-different judgment tasks that do not present a binding problem. Together, these results demonstrate that when seeing one object to the right of another, our impression of simultaneously selecting both objects may be an illusion. We will describe a potential architecture that allows recovery of spatial relations from the pattern of shifts themselves, as show how this flexible processing system could be extended into non-spatial domains (e.g. size or number judgments).

Acknowledgement: NSF

54.22, 2:45 pm

Topological change triggers the attentional blink: Evidence for the topological definition of perceptual units

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The attentional blink (AB) refers to a robust attentional phenomenon that in a rapid serial visual presentation, the detection of T1 leads to a deficit for T2 within a brief period. However, the present studies of AB have rarely addressed the question of exactly what spatial or form attribute of targets and distractors determines the presence and extent of the AB. This may reflect a lack of theoretical framework for understanding the fundamental question in any theory of attention: what attribute of a stimulus defines a perceptual unit that attention selects. We proposed, inspired by the "global-first" topological definition of perceptual unit, a topological hypothesis that topological change (TC) between the targets and distractors presented in a rapid sequence may be perceived as an emergence of new perceptual unit, thus triggers the AB. This hypothesis was tested in 7 experiments. Letters, digits and geometric forms, were used as T1 (e.g. E vs. P), T2 (e.g. H) and distractors (e.g., S/U) for representing TC in holes between them (e.g., P vs. S/U), and meanwhile to control for non-topological factors, including line-segment, shape, color, and semantic elements. The results consistently showed that the TC in holes from distractors to T1 triggered AB, while no AB was observed when T1 and distractors were topologically equivalent. Furthermore, to explain why AB occurred in the previous studies, which didn't specifically manipulated topological property, we replicated the findings by Raymond, Shapiro, & Arnell (1992) and Chun & Potter (1995), and found that in 85% of the trials, there was TC between T1 and distractors located within the range of -3 to +1 lags. In summary, all results consistently

supported our topological hypothesis for the AB in particular, and that a perceptual unit can be defined as something that keeps its topological structure over time in general.

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54.23, 3:00 pm

Attention capture by unique color changes occurs independent of color singletons

Adrian von Muhlenen¹(a.vonmuhlenen@warwick.ac.uk), Markus Conci²; ¹Department of Psychology, University of Warwick, ²Department of Psychology, Ludwig-Maximilians-University Munich

A sudden color change is typically less salient in capturing attention than the onset of a new object. However, recently von Muhlenen, Rempel and Enns (2005, Psychological Science) showed that a color change can capture attention as effectively as a new object provided that it occurs during a period of temporal calm, where no other display changes happen. Experiment 1 used a preview search paradigm where figure-eight placeholders turned into search letters after one second. During (Experiment 1A) or 150 ms before (Experiment 1B) this transition, one of the placeholders changed its color to red. As in previous studies the color change captured attention only when it was temporally unique, that is, when it occurred 150 before display transition. Experiment 2 used the same procedure as in Experiment 1B, except that now items had all different colors. Consequently, the changing item did not turn into a color singleton. Nevertheless, capture was as strong as in Experiment 1, indicating that capture is triggered rather by the local color change than by the sudden appearance of a color singleton. Experiment 3 was again like Experiment 1, but the direction of the color change was reversed, that is, the preview display contained one red item among gray items, which changed its color to gray. Again, attention capture was as strong as in Experiment 1, further supporting the view that attention capture is driven solely by the local color change. Finally, in Experiment 4 all items changed color from gray to red except one, which became a color singleton staying gray. The results showed that all changed item received attentional priority over the unchanged singleton items. Together these results support the view that any temporally unique change captures attention, irrespective of whether this change goes along with the appearance of a singleton or not.

54.24, 3:15 pm

Top-down attentional capture by associated scenes in an object search task.

Noah Sulman¹(sulman@mail.usf.edu), Thomas Sanocki¹; ¹University of South Florida

In a focal contingent capture paradigm (Ghorashi et al., 2003) we demonstrate that subjects search for familiar object categories on the basis of attentional control settings (ACS) that include information about associated contexts. Further, subjects attend to representations of these associated contexts automatically, that is, even when this harms performance in the primary search task. On each trial, observers responded about a cued target object in an RSVP stream of photographs. A wide range of target categories (approximately 70) was employed and the target category changed on each trial. After viewing this sequence of images, observers indicated whether the object was presented (Experiment 1) or which version of the object was presented (Experiments 2 and 3). Critically, on half of trials this target object (e.g. "camel") was preceded by a photograph depicting an associated scene context (e.g. "desert"). Otherwise, the target object was preceded by an unassociated scene. Depictions of associated contexts captured attention and resulted in costs for detection and discrimination tasks. Manipulations of the relative positions of the associated context distractor and the target revealed the time course of this capture effect. Costs only emerge at lags greater than 1 and persist for approximately 500 ms. In addition to demonstrating that observers automatically use contextual information when selecting objects in a search task, these experiments are also a novel demonstration of both the flexibility and limitations of top-down attentional control. The target category changed on each trial and only repeated once in Experiments 2 and 3. Despite the highly variable and rapidly changing target criteria, observers were able to quickly establish representations that

identify task relevant information. While observers could rapidly establish the ACS required to select a task (e.g. find a dog) they could not exclude associated, but task irrelevant, information (e.g. a doghouse).

54.25, 3:30 pm

Attentional capture vs. emotional capture: Potentially separate mechanisms of perceptual disruption

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Emotional stimuli can disrupt perception of subsequent targets at their location, a phenomenon known as emotion-induced blindness (Most et al., 2005). It has been unclear whether the mechanisms underlying this phenomenon reflect a unique impact of emotion on perception or instead are identical to those that would be triggered by any attention capturing stimulus (e.g., Spalek, Falcon, & Di Lollo, 2006). Recently, we found emotion-induced blindness to be spatially localized (Most & Wang, in press): participants searched through two simultaneous RSVP streams for a target while trying to ignore a preceding neutral or emotional distractor, and the targets and distractors could appear either in the same or opposite stream. Emotion-induced target perception impairments in the streams containing emotional distractors but not in the opposite stream. In the current study, we first replicated this spatially localized effect (Experiment 1). We then tested whether non-emotional, but attention-grabbing distractors would elicit similarly localized perceptual impairments (Experiments 2 & 3). In Experiment 2, participants searched for a red letter that could appear within one of two simultaneous RSVP streams of white letters while attempting to ignore a preceding task-irrelevant green letter that could appear in either the same or opposite stream. Experiment 3 was identical, except that participants tried to ignore a task-irrelevant red digit, which could only be distinguished from the target via category membership rather than color. Both the green letter and the red digit disrupted target perception, but they did so in a spatially invariant fashion, with equivalent impairments regardless of whether they appeared in the same or opposite stream as the target. These results suggest that emotional distractors impair target perception via mechanisms of spatiotemporal competition, and that such mechanisms are separable from those triggered simply by the non-emotional capture of attention.

Acknowledgement: NIH Grant 1R03MH091526-01

54.26, 3:45 pm

The role of perceptual load in orientation tuning

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Much previous research has demonstrated that perceptual processing depends on the level of perceptual load involved. Tasks of high perceptual load result in reduced perception of any task-irrelevant stimuli accompanied by reduced visual cortex response. However, it remains unclear whether these effects are mediated by an effect of perceptual load on the strength of neural signals or on the level of noise in the neural coding. We report a study investigating this question in the case of orientation perception. We varied the level of perceptual load in a letter search task presented in a circle surrounding fixation and assessed the effect on orientation discrimination for a vertically oriented Gabor patch presented inside the letter circle (either slightly above or below fixation). The Gabor patch was embedded in bandpass-filtered orientation noise. By varying the mean frequency of the orientation noise we were able to construct orientation tuning curves. The results revealed significant effects of perceptual load on both the amplitude and bandwidth parameters of the tuning curves. High perceptual load during letter search significantly increased the amplitude (i.e. increased the contrast threshold) and led to a considerable increase in the bandwidth, indicating broadened orientation tuning. These results suggest that depleting perceptual resources (when attention is engaged in a high load task) not only reduces the overall percept signal strength but also results in increased noise, thus compromising both the strength and precision of perceptual representations. The results are discussed in relation to previous research on the effects of attention on neural tuning.

Acknowledgement: Wellcome Trust (NL)

54.27, 4:00 pm

Learned control over attention capture is disrupted following medial temporal lobe damage

Joshua Cosman^{1,2}(joshua-cosman@uiowa.edu), Shaun Vecera^{1,2}; ¹University of Iowa Department of Neuroscience, ²University of Iowa Department of Psychology

Our ability to overcome distraction by salient but irrelevant information in the environment relies critically on the acquisition and implementation of effective attentional control settings. It is often hypothesized that these settings are implemented on-line in an effortful, controlled manner, but recent evidence suggests that such settings can be implemented automatically, with past experience being a major determinant of the settings used in a given task context (e.g., Leber & Egeth, 2006a). This suggests that observers store information about the control settings used in a particular task context for later use, allowing these learned settings to be implemented rapidly and automatically when encountering similar tasks in the future. Such an interpretation would necessarily implicate long-term memory processes, and to this end the current study examined the role of the medial temporal lobes, known to be involved in long-term contextual learning, in the acquisition and implementation of such context-specific control settings. A group of patients with severe amnesia due to bilateral medial temporal lobe damage, in addition to neurologically normal and brain-damaged comparison subjects, were trained to use one of two strategies to complete a basic attentional capture task, and were then tested on a similar task in which multiple strategies were available (a la Leber & Egeth, 2006a). Although there was a robust carryover effect in both neurologically normal and brain-damaged comparison participants, no carryover effect was observed in any of the amnesic patients, suggesting that medial temporal lobe structures are integral to generating context-specific control settings. This result demonstrates a novel role for the medial temporal lobes and long-term contextual memory in the control of visual attention and argues that task experience is a critical factor in determining the extent of attentional capture.

54.28, 4:15 pm

Target detection at 50 or 33 ms/picture in RSVP

Mary Potter¹(mpotter@mit.edu), Brad Wyble², Emily McCourt¹, Daniel Stofleth²;

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Detecting a picture in a rapid serial visual presentation (RSVP) on the basis of a verbal title given just before the sequence (e.g., people in a restaurant) has been shown to be surprisingly easy when pictures are presented for about 100 ms (Potter, 1975). In the present study we presented color photographs of a wide variety of scenes at still higher rates, including 50 ms/picture in six-picture RSVP sequences; the sixth picture functioned as a mask and was never the target. Performance given a verbal title was strikingly good: At 50 ms/picture, the hit rate was .71 and the false yes rate was .14, an overall accuracy of .79. Whether or not the subject had detected the target picture, each target-present trial was followed by a forced choice test between two pictures, both of which matched the target title (but only one had been in the sequence). Even with this more severe test, performance was high and significantly above chance at the 50 ms presentation rate: .775 correct. In work in progress, we find that detection performance remains above chance (.725, N=5) when the rate is 33 ms/picture (so that the whole sequence takes only 200 ms), although now the difficult forced-choice task is close to chance, at .57. This work suggests that it is not only global image statistics that can be picked up at high rates of presentation, but also more specific object and gist information.

Acknowledgement: MH47432

Perception and action: Pointing, hitting, reaching, and grasping

Tuesday, May 10, 5:30 - 7:15 pm

Talk Session, Royal Palm 1-3

Moderator: Jody Culham

55.11, 5:30 pm

fMRI reveals a lower visual field preference in dorsal visual stream regions during hand actions

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Humans have been shown to be more efficient when reaching or grasping stimuli in the lower visual field than in the upper visual field. This suggests that the dorsal 'action' visual stream is biased towards processing information in the lower visual field. In line with this, several neurophysiological studies in the monkey have reported that neurons within the dorsal stream over-represent the lower visual field relative to the upper visual field. The present study used slow event-related functional magnetic resonance imaging (fMRI) to examine whether human brain areas implicated in action would show such visual field preferences. We asked ten participants to fixate one of four LEDs positioned in a square such that each LED was at 13° (visual angle) from a centrally presented object. Thus the objects could appear in the upper left, upper right, lower left or lower right visual field with respect to the fixation points. On some trials, participants reached to grasp the object with the right hand and on other trials they passively viewed the object. At the beginning of each trial, participants had to saccade to one of the fixation points and to maintain fixation there for the duration of the trial. By manipulating the position of the LEDs rather than the position of the objects, we ensured that the biomechanics of the movements did not differ across conditions. The superior parieto-occipital cortex and the anterior intraparietal area, brain areas implicated in the control of hand actions, showed significantly higher activation when participants grasped objects presented in the lower visual field than in the upper visual field. However, no visual field preferences were observed in these regions during passive viewing. These findings suggest that the neural responses within dorsal visual stream regions may reflect a lower visual field advantage specific to visually guided actions.

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55.12, 5:45 pm

Testing whether humans have an accurate model of their own motor uncertainty in a speeded reaching task

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The distribution of the endpoint of a speeded reaching task is typically bivariate Gaussian in form. This distribution determines the subject's probability of hitting targets of any sizes and shapes. We used staircase methods to determine whether subjects can correctly order the probability of hitting targets differing in size and shape in a speeded reaching task, testing whether they had an accurate model of their motor uncertainty.

Experimental phases: Training. Subjects completed 300 trials of a speeded reaching task, in which they touched a circle on a touch screen within 400 milliseconds. Probability Judgment. On each trial, subjects judged which of two shapes, a rectangle and a circle, was easier to hit. The rectangle was either 4:1 (horizontal) or 1:4 (vertical), and had five possible sizes, tuned to each subject's motor variance. We used a staircase method to determine the radius of the circle the subject judged to be as easy to hit as each of the ten rectangles. Area Judgment. An experimental control identical to the previous phase but subjects judged area. Twelve naïve subjects participated.

Results: (1) While the motor error distributions for all subjects in training were anisotropic bivariate Gaussian, elongated in the vertical direction, none of the subjects correctly compensated for their anisotropy in judging the probability of hitting rectangles differing in orientation. (2) The probability judgments of six subjects were consistent with judgments based on the best-fit isotropic Gaussian approximating their own motor error. (3) The

remaining six subjects made judgments consistent with a flatter motor error distribution than their actual. (4) Subjects who accurately estimated probability failed at estimating area and vice versa. Such a relationship between two, in principle, distinct estimation tasks suggests some common process or representation underlying them both.

55.13, 6:00 pm

Recalibration of eye and hand reference frames in age-related macular degeneration

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When vision is lost in the central field, a new peripheral retinal locus (PRL) is adopted as the oculomotor reference for fixating isolated targets. This same locus is thought to act as a "pseudo-fovea" for saccadic behavior. Shifting the oculomotor reference frame presents a potential conflict for coordinating eye and hand movements. In this study, we examine the saccade and reaching behavior in patients with age-related macular degeneration (AMD) during a rapid pointing task. METHODS: Participants had long-standing bilateral wet AMD. Central field loss was greater than 10° in diameter as measured with microperimetry. During experimental sessions, subjects first fixated a central target with the PRL and pressed a button to begin the trial. A high contrast dot appeared at eccentricities ranging from 2°-12° in a block design, in one of eight directions. Subjects were asked to make a rapid point to this target. The reach endpoint was recorded with a touch sensitive LCD and eye movements were tracked. RESULTS: Overall, saccade latencies and reach times were comparable to that found for normal observers, and declines were also observed in endpoint accuracy and precision as a function of target distance (Ma-Wyatt & Renninger, VSS 2011). The PRL moved from fixation toward seen targets, indeed acting like a "pseudo-fovea". When the target was unseen (in the scotoma), searching behavior ensued. Unlike saccades and reaches in normals, however, the pattern of movement endpoints were not radially oriented and hypometric. Instead, a positional bias along the PRL-to-fovea axis was evident in which saccade endpoints were shifted away from the fovea, and the reaching endpoints shifted toward the fovea. CONCLUSION: Although movement dynamics appear normal, the loss of radial saccade endpoint patterning and the opposing biases in saccade and reach endpoints suggest that recalibration of these motor reference frames is incomplete.

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55.14, 6:15 pm

Me or Not Me: Causal Inference of Agency in goal-directed actions

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The perception of own actions is affected by both visual information and predictions derived from internal forward models [1]. The integration of these information sources depends critically on whether visual consequences are associated with one's own action (sense of agency) or with changes in the external world unrelated to the action [2,3] and the accuracy of integrated signals [4,5]. The attribution of percepts to consequences of own actions should thus depend on the consistency between internally predicted and actual visual signals.

METHODS. To test this idea, we used a virtual-reality setup to manipulate the consistency between pointing movements and their visual consequences and investigated the influence of this manipulation on self-action perception. We then asked whether a Bayesian causal inference model, which assumes a latent agency variable controlling the attributed influence of the own action on perceptual consequences [2,3], accounts for the empirical data: if the visual stimulus was attributed to the own action, visual and internal information should fuse in a Bayesian optimal manner, while this should not be the case if the percept was attributed to external influences. The model assumes that both the visual feedback and the internal estimate are directly caused by the (unobserved) real motor state.

RESULTS AND CONCLUSION. The model correctly predicts the data, showing that small deviations between predicted and actual visual information were attributed to one's own action. This was not the case for large deviations, where subjects relied more on internal information. We discuss

the performance of this causal inference model in comparison to alternative biologically feasible statistical models, applying methods for Bayesian model comparison.

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55.15, 6:30 pm

Temporal Aspect of Motor Performance's Effect on Perception

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While motor performance can modify perception (Witt & Proffitt, 2005; Witt, Linkenauger, Backdash, & Proffitt, 2008), the time course of this change remains unclear because previous experiments have assessed perception only after the experimental action has occurred. To address this issue, we had participants throw a ball into various sized holes and report, in a haptic (experiment 1) or verbal manner (experiment 2), how large the hole appeared to be. Participants gave this report under one of three conditions: 1) concurrent with their throw of the ball, using video recording of unseen fingers; 2) immediately after the throw, while the hole is still visible; and 3) immediately after the throw, while the hole is not visible. The results were divided into successful and unsuccessful trials. Perception was altered only in Condition 3 for both experiments, indicating that the effect of performance on perception occurs only after the act of throwing, in a style similar to memory.

55.16, 6:45 pm

Anticipation of sabre fencing attacks

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Humans are able to anticipate and react to events conveyed by the visual information in the world around them. Various sports act as a prime example of this. In sabre fencing, for example, the athlete obtains information about their opponent's movements and uses it to stage attacks as well as anticipate and react in defense. In the present study, we use motion capture to obtain the dynamic biological motion involved in various traditional sabre attacks. Using the methods employed by Diaz et al. and Mantovani et al., we examine the sources of movement information available that allows the defender to anticipate the attacker's intended target. The results of our analysis were compared to the eye fixation results of Hagamann et al. to determine whether the sources that our analysis found to be rich in information were the same as those fixated on by human fencers. In a subsequent study, the motion capture data was used to create a class of artificial stimuli which included temporal and/or spatial occlusion. These were then viewed by human fencers who were asked to make real time judgments as to where the attacks were aimed. Results indicated a variety of reliable information sources. The relative importance of specific sources appeared to change over the time course of an incoming attack, and across the different skill levels of the fencers tested.

55.17, 7:00 pm

Learning to reach for 'invisible' objects: evidence for 'blindsight' in normal observers.

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Blindsight refers to the ability of patients with visual cortex damage to detect, localise or discriminate visual stimuli that they deny 'seeing'. In this study we sought to create an analog of blindsight in normal observers using binocular masking via continuous flash suppression. We had participants reach toward and pretend to grasp an imaginary object represented by a pair of parallel lines, oriented horizontally or vertically, made 'invisible' via masking. The dependent variable was the orientation of the hand, horizontal or vertical, at grasp. Over a period of training (six 100 trial sessions) during which trial-by-trial feedback was provided, participants showed a significant improvement in their ability to orient their hand to grasp the 'invisible' target. No such improvement was evident when other partici-

pants responded using only verbal responses, even with a matched period of training. Trial-by-trial reports of subjective visibility and confidence in performance revealed that, while participants never reported 'seeing' the target, performance was highly correlated with confidence. These data have important implications for the treatment of cortically blind patients, and highlight the indistinct boundaries between what we consider visible and invisible inputs.

Motion: Integration

Tuesday, May 10, 5:30 - 7:15 pm

Talk Session, Royal Palm 4-5

Moderator: Ikuya Murakami

55.21, 5:30 pm

Neural activity underlying the integration of trajectory information

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The perception of optic flow relies on the integration of many local pieces of information to generate a global percept of motion direction. This processing of motion requires mechanisms that can integrate information over space and time. Here we investigate the temporal integration of motion direction across early visual areas using EEG source-imaging and participants who each had fMRI-mapped retinotopic and functionally defined visual areas. These individually defined regions of interest allowed us to average data across participants in a way that respects individual differences in sulcal anatomy and electrode placement.

We used a random-dot motion stimulus with individual dots updating at 30 Hz that alternated between globally coherent motion and incoherent motion at 1 Hz. During the incoherent interval, each dot had a random direction on each update, but during the coherent interval we systematically varied the duration any single dot spent on a consistent trajectory before being extinguished and replaced with a dot in a new random location. The local information provided by the individual dots was tagged with 30 Hz while the global alternation from coherent flow to incoherent flow was tagged at 1 Hz. These tags enable us to distinguish responses associated with global and local information.

We find that activity in dorsal visual areas increased monotonically with longer dot trajectories. While activity from human MT complex differentiates coherent from incoherent global flow, its response does not grow with increasing consistency of trajectory. In addition we find a signature of nonlinear coupling between local information updates and the presence of coherent motion. Specifically, in dorsal visual areas the response at the frequency tagged by the local dot refresh rate increases during the coherent motion interval. These results suggest that dorsal visual areas such as V3A are responsible for the integration of motion information over extended trajectories.

55.22, 5:45 pm

The effects of size and speed on perceived 3D object motion at different distances

Junjun Zhang¹(junjunz@uci.edu), Myron Braunstein¹, George Andersen²; ¹University of California, Irvine, ²University of California, Riverside

Variations in projected size and projected speed provide information about the motion of objects in 3D space. Projected speed information is available in both polar and parallel projections (Todd, 1984), but projected size is only informative about changes in depth in perspective (polar) projections. The usefulness of size information in judging 3D motion should therefore diminish faster with increased viewing distance than the usefulness of speed information. We therefore predicted an interaction between size information and speed information in determining the accuracy of 3D motion judgments as simulated viewing distance was increased. The stimuli were simulated motions of a ball in a convex circular arc in a horizontal plane at eye level. The curvature of the ball's trajectory was indicated either by changes in both the projected size and projected speed or by changes in the projected size only or in the projected speed only. There were three levels of curvature and three levels of simulated eye distance. Initial sizes and speeds were randomized across displays. Observers were presented with two displays on each trial, both at the same simulated eye distance and both providing the same information for curvature (size, speed or both). The displays differed in the curvature of the ball's trajectory and the

observer's task was to indicate which display showed the more curved trajectory. Accuracy was higher with size information alone than with speed information alone at the closest viewing distance. At the greatest viewing distance, accuracy with either size information alone or speed information alone dropped to near chance levels, but accuracy remained high when both types of information were available. This indicates that even when speed information does not provide a high level of accuracy in isolation, it can combine with size information to markedly increase the level of accuracy available at increased distance.

Acknowledgement: NIH grant EY18334

55.23, 6:00 pm

Motion integration and segregation modulated by surrounding motion

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When two visual motion components are simultaneously presented in the same region of the visual field, they may be perceptually integrated or segregated depending on the directional difference (van Doorn & Koenderink, 1982). However, influences of surrounding motions on such motion integration/segregation are still unknown. In the present study, we examined the functional relationship between center-surround interaction and motion integration/segregation. We presented two vertical random-dot motions in similar directions (e.g. ± 45 deg from upward) in the center and a purely vertical random-dot motion (up or down) in the surrounding annulus. Subjects were asked to judge whether the central stimulus was seen as one coherent motion or two transparent motions. Subjects were also asked to report the perceived directions of the central motions by directional matching. The central stimulus was more frequently categorized as two segregated motions when the surrounding stimulus was moving upward. On the contrary, the central stimulus was more frequently categorized as one coherent upward motion when the surrounding stimulus was moving downward. These influences of surrounding motion on the perceived direction and motion segregation of the center decreased at faster central motion speeds. Since motion streaks were more readily observed in the central stimulus at faster central speeds at which the influence of the surround became weaker, this result refutes the hypothesis that the influence of the surround is mediated by a perceptual bias on motion streaks. Furthermore, we found that these psychophysical results were qualitatively replicable by a population coding model including surround suppression and response normalization in area MT neurons (Tajima et al., 2010). The present results suggest that motion segregation and integration are determined based on the directional representation modulated by the surrounding motion. Surround modulation in population activities may play a key role in the perceptual switching between motion integration and segregation.

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55.24, 6:15 pm

Combination of optic flow fields and stereoscopic depth fields in the encoding of self-motion

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The principal visual cue to self-motion (egomotion) is optic flow, which is specified in terms of local 2D velocities in the retinal image without reference to depth cues. However, in general, points near the centre of expansion of natural flow fields are distant while those in the periphery are closer, creating gradients of horizontal binocular disparity. To assess whether the brain combines disparity gradients with optic flow when encoding egomotion, stereoscopic gradients were applied to expanding dot patterns. The gradients were radially symmetrical, forming a cone with the apex at the centre of expansion. The depth cues were either consistent with self-motion (concave disparity cone, as in a tunnel) or inconsistent (convex cone with central dots near, peripheral dots far). The stimuli covered the same range of disparities (± 52 minarc relative to the fixation plane) and had a diameter of 23 deg. They were presented via binocular LCD goggles during 3T MRI scanning. To maintain attention, participants performed a demanding counting task at fixation. The BOLD activity generated was compared in a wide range of pre-defined visual regions in 13 participants with good stereo-acuity. Three regions reliably responded more strongly to consist-

tent than inconsistent depth when added to expanding flow. These were (i) hV6, in the parieto-occipital sulcus, (ii) a small region in the precuneus that we refer to as PcM and (iii) vestibular-visual area PIVC, all of which can be identified by comparing responses to egomotion-compatible and -incompatible flow (Cardin & Smith, *Cerebral Cortex* 2010, 20, 1964). All other visual areas examined (V1-V3B, V7, MT, MST, VIP, CSv) responded well to the stimuli but were indifferent to their depth-flow relationship. The results confirm the involvement of V6, PcM and PIVC in encoding egomotion and suggest that depth and flow cues may be integrated in an egomotion-dependent way in these regions.

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55.25, 6:30 pm

The Perception of Body Movements: The Role of Biological Motion and Form

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The perception of others' body movements is subserved by a network of lateral temporal, parietal, and premotor brain areas, here called the action perception system (APS). Using fMRI adaptation, we explored selectivity for biological motion and/or biological form in this network. Participants watched 2 s clips of recognizable actions of a human (biological motion and form), a humanoid robot (mechanical motion and form), or an android (mechanical motion, biological form). The latter conditions actually were of the same robot, with identical kinematics, videotaped with or without human-like skin. Each movie clip was preceded by the same movie or a different movie and we explored brain areas that showed adaptation. With the exception of left extrastriate body area, which showed adaptation for biological appearance (human and android), the APS was not selective for motion or form per se. Instead, specific responses were found to the mismatch between motion and form: Whereas fMRI adaptation results for the human and robot (the agents that differed in both motion and form) conditions were similar to each other, there were additional areas of adaptation for the android condition. Most notably, in bilateral anterior intraparietal sulcus, a key node in the APS, we found significantly more adaptation for the android than the other agents, indicating the congruence of form and motion is an important factor to consider. We interpret these data in the predictive coding framework (Rao and Ballard, 1999) and suggest that these additional responses to the android reflect increased prediction error as the brain negotiates an agent that looks biological, but does not move biologically. These results contribute to our goal of identifying the functional properties of the APS, and may also help demystify the "uncanny valley" hypothesis from robotics, whereby artificial agents that are too human-like can evoke negative reactions (Mori, 1970).

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55.26, 6:45 pm

Seeing the direction of a crowd: Ensemble coding of biological motion

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When perceiving groups of features, we may rely on ensemble codes of pooled feature signals that precisely describe the average (i.e., the gist) but limit access to the details (Herman & Whitney, 2007). Here we demonstrate the use of an ensemble code to perceive the average direction of a walking crowd of people. We briefly presented crowds of twelve non-overlapping point-light walkers containing different amounts of direction variability (i.e., walkers had identical or increasingly divergent headings). Observers then estimated the average direction of the crowd. We used an equivalent noise model (Dakin, 2001) to measure response variability as a function of direction variability. This allowed us to estimate the number of walkers pooled to perceive crowd direction and unambiguously reveal the use of ensemble coding. To separately measure the contributions of human form and local motion to perceiving a group's direction, we also presented crowds of static walkers (form without local motion) and point-

scrambled walkers (local motion without form). Results were consistent with ensemble coding. On average, observers pooled the directions of five walkers to estimate the direction of a crowd. Direction estimates for crowds with moderate variability were only as noisy as estimates with a homogeneous crowd for all observers, and only as noisy as estimates with a single walker for most observers. Increases in crowd variability only raised response variability when crowd variability was already high. This pattern suggests that observers involuntarily perceived the average direction of the crowd. The ensemble code incorporated both form and local motion, as direction estimates were worse with form or local motion alone than with both combined. In summary, the visual system creates an ensemble code for perceiving the average direction of a crowd. This summary representation is likely generated in high-level visual areas after the convergence of form and motion signals.

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55.27, 7:00 pm

Biological motion detection does not involve an automatic 'perspective taking'

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Concurrent motor execution influences action perception. Previously, we presented evidence for a spatio-temporal tuning of this action-perception coupling (Christensen et al., *JoV*, 2009, 9(8)). Facilitatory influences were found only for synchronous and spatially similar actions. Additionally, when observing others, subjects automatically tend to embody another person's visuo-spatial perspective (Thirioux et al., *Brain Cogn*, 2009, 70(2)). This raises the question, whether the performance increase for spatially congruent stimuli depends on such 'disembodied self-locations' and whether a body- or visual-centered frame of reference determines spatial similarity. **METHOD:** Point-light stimuli of waving arms embedded in a scrambled mask were presented in a detection task. Participants were instructed to interpret the point-light stimuli either as person seen from the front or from behind. The displayed stimulus (right or left arm) matched the executed arm movement either in a visual or in a body-centered frame of reference. The detection thresholds were determined by varying the number of noise dots in the stimuli; compared to a baseline without concurrent execution of motor actions.

RESULTS / CONCLUSION: Significant facilitation of biological motion detection by concurrent motor execution was observed only when the visual stimulus matched the executed movement in a visual frame of reference. The instruction to interpret the stimulus in different body-centered perspectives did not influence the results, even if we controlled for subtle kinematic differences between front and back views. We conclude that the modulation of biological motion detection occurs in a visual frame of reference and does not include active perspective taking by the observer.

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Face perception: High-level features

Tuesday, May 10, 3:00 - 7:00 pm

Royal Palm 6-8, Poster Boards 301 - 316

56.301 Face Processing Abilities Relate to Career Choice

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A person's ability to process faces could potentially impact the quality of their social interactions and affect their success in careers that require high levels of social interaction. Indeed, face recognition ability varies greatly in the normal population, largely due to genetic factors (Wilmer et al, 2010), and facial emotion recognition ability has also been shown to vary widely (Baron-Cohen et al., 2001). However, the everyday correlates of individual differences in face processing abilities remain largely unstudied. Here, we investigated the relationship between career choice and an individual's ability to remember faces (via the Cambridge Face Memory Test (CFMT), Duchaine & Nakayama, 2007) and label facial expressions (via the Reading the Mind in the Eyes Test (RMET), Baron-Cohen et al., 2001). Through our website www.testmybrain.org, 5396 participants completed the CFMT, the RMET, and a questionnaire about their careers. There was significant variation between careers on both the CFMT ($F = 3.04, p < .001$) and the RME ($F = 2.02, p < .02$). Individuals with careers in visual arts/graphic design and law performed significantly better than average on both tests, while those with careers in computers/IT performed significantly worse than average on the CFMT, but within the normal range on the RMET. A particularly significant effect was found for individuals with careers in visual arts/graphic design, who performed over a third of a standard deviation better than average on the CFMT ($d = .35, t = 3.6, p < .001$). These results document a clear relationship between face processing abilities and choice of career.

56.302 Reading the Lie in the Eyes: The Production and Detection of Tactical Gaze Deception

Joshua New¹(jnew@barnard.edu), Michelle Levine¹, Chloe Cheimets¹; ¹Barnard College, Columbia University

Interpreting eye gaze is a critical faculty for social interactions – one important component being that of reflexive gaze following for establishing joint attention. However, because gaze is a typically great signal of intentions, it can also be used to tactically deceive others – allowing for an arms race between the production and detection of deceptive gaze. Using a signal detection design within a spatial cuing task, we evaluated how well participants could 1) produce deceptive directed gazes amongst honest directed gazes, and 2) discriminate between deceptive and honest directed gazes in others. In groups of four, participants were matched with each of the other participants in turn. In each match, participants alternated between two roles. "Viewers" sat in front of two side-by-side monitors and "responders" sat behind the monitors, with an unobstructed view of each other between the monitors. Viewers were instructed (equally and randomly across trials) either to gaze "honestly" at an appearing probe or to gaze "dishonestly" at the monitor opposite the probe. Responders attempted to report which monitor the probe appeared on. In honest trials, both participants were rewarded for correct responses, or penalized for incorrect responses. In dishonest trials, viewers were rewarded for incorrect responses (successful deceptions), and responders penalized. Responders were rewarded for correct responses (detected deceptions), and viewers penalized. As with many types of deception, overall sensitivity for detecting gaze deception was low and responses were very conservative – deceptive gazes were mistaken as honest far more than the reverse. However, the ability to discern deceptive gazes can improve markedly with exposure to an individual, but such improvement did not necessarily carryover to new individuals. There were large individual differences – a small number of participants quickly reached near-perfect performance in discriminating between honest and dishonest gazes whereas others were persistently incapable of doing so.

56.303 Neural face coding is shaped by race

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Human populations can be categorized by using salient phenotypic traits, a visual process defining the social concept of race. Race markedly impairs one of the most critical and specialized skill humans possess: the recognition of conspecifics. Humans are significantly better at recognizing Same-Race (SR) than Other-Race (OR) faces, feeding the popular belief that OR faces all look alike. Theoretical (Valentine, 1991 – figure 1a) and computational (e.g., Caldara & Abdi, 2006 – figure 1b) Norm-Based Multidimensional Face-Space Models (NBMDFSM) have provided a consistent account for this universal Other-Race Effect (ORE). In NBMDFSM, efficient SR face identification is achieved by sparser coding across diagnostic dimensions for SR compared to OR face-exemplars, a by-product of visual experience. Neural evidence for NBMDFSM coding has been found with fMRI in humans and single-cell recordings in monkeys. Surprisingly, whether and where such neural face coding subserves the laws predicted by NBMDFSM of the ORE is unknown. We measured Western Caucasian (WC) and East Asian (EA) observers' BOLD signals in functionally defined face-selective Region of Interest (ROI – Fusiform Face Areas (FFA) and Occipital Face Areas) while they perceived normalized WC and EA faces (10 identities per race). We then computed Representational Dissimilarity Matrix (RDM – Kriegeskorte et al., 2008) in each ROI independently, by correlating the BOLD response elicited by each identity within a race with the remaining 9 across the multidimensional voxel population (figure 1c). We found significant higher RDM r-values for OR compared to SR faces in the FFA, relating to prototypical (less distinctive) activation patterns for OR faces in both groups of observers. We used RDM to link neural face representations with psychological and computational NBMDFSM of the ORE. This multidimensional voxel mapping quantified coding efficiency in the FFA for individual SR faces. This finding has profound implications for the understanding of the ORE and face perception.

56.304 No own-race advantage for holistic face processing in Chinese participants

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Recent evidence suggests that stronger holistic processing of own-race faces may underlie the well-established own-race advantage for face memory. Across a number of studies Caucasian participants have demonstrated significantly larger holistic processing effects for Caucasian over Asian faces. However, Asian participants have shown a consistently different pattern: similar sized effects for both Asian and Caucasian faces. Here, Experiment 1 replicated these previous findings using Tanaka & Farah's (1993) part-whole task. Caucasian Australians displayed a significantly larger whole face advantage for Caucasian than Asian faces, while Hong Kong Chinese showed no race-of-face differences in holistic processing. Additionally, we included an inverted face condition to investigate the possibility that results for Asian participants reflect a domain-general global processing bias. Results suggest that Asian participants, unlike Caucasian participants, use face-specific holistic mechanisms to process both own- and other-race upright faces. Experiment 2 used the part-whole task in conjunction with Palermo & Rhodes' (2002) flanker task. In the study phase of each trial the part-whole target was flanked by two faces. Participants performed an across-viewpoint identity-matching task (same/different) on the flanker faces while simultaneously encoding the central target. The presence of holistic processing for the flanker task is argued to disrupt holistic processing of the targets. For Caucasian participants holistic processing for own-race targets was reduced only when the flanker faces were Caucasian. For Asian participants both Asian and Caucasian flankers interfered with holistic processing for own-race targets, however no reduction in holistic processing for other-race targets was observed for either race of flankers. Results for this task again support a difference between Asian and Caucasian participants in holistic processing for other-race face. Together

these results suggest that, at least for Asian participants, differences in the strength of holistic processing do not explain differences in memory for own- and other-race faces.

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56.305 The complete design lets you see the whole picture: Differences in holistic processing contribute to face-inversion and other-race effects

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Faces are processed holistically, which is often measured using the composite paradigm, a matching task requiring selective attention to part of a face. One popular index of holistic processing (HP) – the alignment effect used in the partial design – is confounded with response biases, whereas a different measure – the congruency x alignment effect used in the complete design – produces a more valid measure of HP. Because the two measures can yield different conclusions, we re-visit the role of HP in two phenomena where the complete design has not yet been used: the face-inversion effect (FIE) and the other-race effect (ORE).

Recognition of inverted faces (Yin, 1969) or upright faces of an unfamiliar race (Meissner & Brigham, 2001) is often impaired, with a reduction in HP posited as the basis of reduced performance (Rhodes et al., 1989; Hole, 1994). However, support for this claim has been mixed (Sekuler et al., 2004; Stokes et al., VSS 2010) and composite studies of these effects have only used the partial design. Here we obtain categorically different conclusions regarding the contributions of HP to the FIE and ORE depending on how HP is measured.

When investigating the FIE via the composite paradigm using the partial design, HP was only observed for upright but not inverted faces. With the complete design, however, inverted faces were also processed holistically at longer exposure durations. Similarly, when Caucasian and Asian participants were tested with same- and other-race faces, the partial design failed to capture an ORE in HP. In contrast, a significant ORE was observed using the complete design. Additionally, in both experiments, only partial design measures correlated with response bias.

HP was reduced but not abolished for other-race faces and delayed for inverted faces, which is consistent with reduced processing efficiency when objects of expertise depart from familiar conditions.

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56.306 The other-race effect is not ubiquitous

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The fact that own-race faces are easier to recognize than those from another race (the other-race effect or ORE) has been widely cited. Nevertheless, recognizing the identity of a face is a complex task among many others; hence it might be premature to conclude that own-race faces are always easier to process. We investigated whether same-race faces still have a processing advantage over other-race faces when only ethnicity-related information is available to differentiate between faces. We morphed the ethnicity of 20 Caucasians and 20 Asians faces toward their other-race counterpart while keeping their idiosyncratic, identity-related features. Morphing was done at three levels (20%, 50%, and 80% toward the other race). The task for two groups of participants (25 Tübingen and 26 Seoul participants) was to report which face looks more Caucasian (or Asian) after looking at the original face and a morphed face sharing the same idiosyncratic features. Both faces were presented side by side on a computer monitor in one task and sequentially in another task. Importantly, we found no evidence for an ORE in participants' performance and no performance difference between Tübingen and Seoul participants. Both groups were equally good and equally fast at comparing the ethnicity of two faces regardless of the task, the ethnicity of the faces and the question asked. However, we did find evidence that Seoul

and Tübingen participants used different viewing strategies. By investigating their eye-movements in the sequential task, we found that the ethnicity of participants affected fixation durations on specific areas of the face, especially the nose. Also, the type of questions asked and stimulus race altered the pattern of eye movements. These results suggest that although Caucasians and Asians were equally good at dealing with ethnicity information of both races, they might employ different viewing strategies.

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56.307 Training with Same-Race Faces Improves Holistic Processing of Other-Race Faces

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The other-race effect (ORE), the finding that same-race (SR) faces are better remembered and discriminated than faces of other races (OR), has been consistently demonstrated in a variety of tasks and has been associated with better holistic processing of OR faces compared to SR faces. The mechanisms underlying the ORE are currently debated: expertise models claim that repeated exposure and individuation of SR faces account for the ORE, while social-cognitive models argue that individuation resources are allocated to in-group members, but not out-group members. Previous studies demonstrate that it is possible to reduce the ORE by explicitly instructing participants to individuate OR faces or by administering intensive (multi-session) individuation training with OR faces. The possibility of reducing the ORE by training with SR faces, however, has not been explored, and would be a key test of the assumption of the expertise model: that expertise gained with SR faces would not generalize to OR faces. The current study investigated whether training with SR faces can generalize to improvements in processing of OR faces, thus reducing the ORE. Specifically, Caucasian participants performed a 10-day training program that aimed to focus attention on configural and holistic aspects of SR faces. Participants were assessed pre- and post-training on processing abilities of SR and OR (Korean) faces using the Part-Whole Task. Participants showed an overall improvement on OR faces, driven by increased accuracy on OR whole trials. For several participants, holistic processing of OR faces matched that of SR faces. These findings are inconsistent with the assumption of the expertise model, and suggest individuation skills can transfer across races. The current training may accomplish this by creating an automatic bias to encode configural and holistic aspects of all faces, overcoming the social-cognitive bias to process OR faces in a more categorical and less configural manner.

56.308 Eyes like it, brain likes it: Tracking the neural tuning of cultural diversity in eye movements for faces

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Eye movement strategies deployed by humans to identify conspecifics are not universal. Westerners preferentially fixate the eyes and mouth during face recognition, whereas strikingly Easterners focus more on the central facial region. However, when, where and how Preferred Viewing Locations (PVLs) for high-level visual stimuli are coded in the human brain has never been directly investigated. To this aim, we simultaneously recorded eye movements and electroencephalographic (EEG) signals of Western and Eastern observers while they performed face identification of learnt identities. To avoid complex EEG artifacts generated by multi-oriented saccades, we defined 9 equidistant Viewing Positions (VPs) covering the internal facial features and presented the faces centered on a random VP for 100ms (Figure 1), hence controlling for foveal and extrafoveal information sampling. The fixation maps extracted from a prior free-viewing condition corroborated cultural diversity in PVLs (Figure 2) despite similar behavioral performance. Conventional component-based electrophysiological analyses revealed only sensitivity to VPs on the P1 component. However, to properly establish potential modulations of EEG signals as a function of PVLs, we extracted the average Z-scored fixation intensity from the fixation maps around non-overlapping VP regions (VPZs). Then, we computed a component-free data-driven spatio-temporal regression between the VPZs and EEG amplitudes (Figure 3). This novel approach revealed, in both groups of observers, a marked direct relationship between VPZ fixation intensity

and the amplitudes of the EEG around 350ms over the well-defined face-sensitive N170 network: the larger the EEG amplitudes, the greater the VPZ on the matching VPs. This effect was unrelated to a burst of microsaccades occurring in this time window. Our data show that cultural fixation preferences for faces are related to identical post-perceptual neurophysiological responses over the occipito-temporal cortex. Humans from different cultures deploy distinct eye movement strategies, but they crucially rely on a universal neural tuning.

56.309 Co-localization of human posterior STS during biological motion, face and social perception

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Background. Neuroimaging studies have revealed that regions in the superior temporal sulcus (STS) show activity during biological motion perception (Grossman et al. 2000), detection of face identity or gaze direction (Hoffman and Haxby, 2000), and also during understanding concepts of social action (Martin and Weisberg, 2003). We aim to determine whether or not the human STS has a common area for all of these tasks. Method. Subjects participated in multiple localizer tasks designed to activate the human posterior STS. These tasks included 1) point-light biological motion versus motion-matched scrambled controls (e.g. Grossman and Blake 2001), 2) social vignettes depicting geometric shapes engaged in social or mechanical actions (i.e. Martin and Weisberg, 2003), and 3) stationary faces versus pixel-scrambled faces. Using a GLM analysis, we first identified the posterior STS from each localizer for the individual subjects. We then conducted a whole brain conjunction analysis across all three tasks to determine the common regions that were common to all of them. Results. The conjunction analysis revealed bilateral regions common to all localizers in the STS, EBA/hMT+ (Extrastriate Body Area, and Medial Temporal area) and in the dorsolateral prefrontal cortex (DLPFC). Conjunction analysis for only the face and biological motion tasks revealed additional areas in the fusiform gyrus (e.g. fusiform face and body areas). Larger areas of DLPFC and unilateral areas near the sylvian fissure (Left Hemisphere) were found with the conjunction of ROIs between the biological motion and social mechanical tasks. The conjunction between face and social mechanical ROIs revealed additional areas in the fusiform gyrus. Conclusions. This study suggests that a common network of brain areas, including a specific portion of the posterior STS, is involved in processing socially relevant information across these three different tasks.

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56.310 A region in the Posterior Superior Temporal Sulcus (pSTS) appears to be selectively engaged in the perception of social interactions.

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The ability to perceive and understand social interactions between others is a fundamentally important cognitive skill, yet almost no research has investigated its brain basis. Here, we hypothesized that the posterior superior temporal sulcus (pSTS) – an area implicated in many other aspects of social perception – plays a key role in perception of social interactions. To test this hypothesis, we scanned subjects with fMRI while showing them point-light movies of two people interacting with each other (e.g. one person gesturing to another) versus point-light depictions of two people performing independent (non-interactive) movements (e.g. one biking, the other walking). Consistent with our hypothesis, in 6 of 8 subjects we found a region in pSTS that responded significantly more strongly during perception of social interactions than perception of “independent” actions. This region showed a significantly greater response to interaction than independent motions in independent data from the same subjects. We further tested the “interaction” selectivity of this pSTS region in independent data and found a significantly greater response to point-light interaction movies than i) movies showing the same motions but in which the characters performed their movements facing away from each other ($p=.05$), and ii) full-color movies of moving faces and bodies. These and other analyses suggest that the interaction-selective region in pSTS overlaps only slightly with regions showing selectivity for face perception and simple biological motion perception (identified in separate localizer scans). These results not

only further implicate the pSTS in complex social perception but also suggest that there is a region in the pSTS specifically engaged in perceiving social interactions between others.

56.311 Visual attractiveness is leaky (3): Effects of emotion, distance and timing.

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Since emotion is nonselective, emotional evaluation of object may also be nonselective. In particular, attractiveness of an attended object may be affected by that of “neglected” surrounds. We reported such an implicit leakage of attractiveness from surrounding faces (FCs) to an attended geometric figure(GF) (VSS’10 (1)), or from the “neglected” FC to the hair attached to it((2)). Here, we explore effects of emotional expression and gaze direction of the FCs, and distance/timing of the surrounds on the attractiveness of the central GF.

There was a central GF surrounded by four FCs. The task was always to evaluate attractiveness of the GF on a 7-point scale. There were two different viewing instructions, assigned to two participant groups, respectively (“Ignore the FCs,” or “Examine the whole image however you want, but evaluate the GF only”). The latter group was further divided into two groups, depending on the post-hoc eye movement analysis (viewed the whole, or still neglect the FCs), and analyzed separately. We manipulated (a)relative baseline attractiveness between FCs and GF, (b)emotional expression(neutral, happy, angry), (c)gaze direction(straight, towards the center, away), (d)distance(close, far), and (e)timing(simultaneous, FCs first). Among them, (a) were randomized within block whereas (b)-(e) were assigned to separate blocks.

We found that: 1) The main effect of FC attractiveness was mostly significant. It confirms that attractiveness is indeed leaky, i.e. the “ignored” surrounding objects can modulate attractiveness of the attended. 2) There was a paradoxical relationship between how much the surrounds were explored vs. how much the attractiveness leaked from them. The more they were neglected, the more leakage was observed. 3) Emotional expressions of FCs affect the GF attractiveness, but interacting with the FC attractiveness. 4) Distance and timing both had expected effects, but interacting with the FC attractiveness. Gaze directions had only weak effects.

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56.312 Visual attractiveness is leaky (4): Effects of non-social stimuli and the relationship to distance and timing

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If you go to a car show, cars are presented by beautiful women. It has been known that positive social stimuli seem to affect attractiveness perception of non-social stimuli. Moreover, such a leakage of attractiveness can be against the observer’s intention (VSS’10 (1) and (2), VSS’11 (3)). However, will standing by a gorgeous sports car make them appear even more attractive? The first purpose of the current study was to explore whether only the perceived attractiveness of non-social stimuli can be influenced by social stimuli, or rather the effect can be the other way around, too. The second purpose was to explore whether this assumed leakage of attractiveness can be modulated by a) the distance and b) the timing of the surroundings in relation to the target object. We used three types of stimulus configurations 1) A center geometrical figure (GF) surrounded by four faces (FCs), 2) a center FC surrounded by four GFs and 3) a center FC surrounded by four FCs. In each of these set-ups, we manipulated the relative baseline attractiveness between the surrounding and the central objects, and either the timing (simultaneously, or surroundings first by 2 sec.), or the distance (close or far). The task was to evaluate the attractiveness of the central object, while neglecting the surroundings. We found a significant influence on the attractiveness-ratings of faces by non-social, as well as social stimuli. Thus, the claim that attractiveness is leaky does not only hold for an influence of social stimuli, but also of non-social stimuli. In addition, we found that the influence is significantly stronger when the surroundings are in close spatial proximity to the target. The results for the timing revealed a tendency for the influence to be stronger when the surroundings are presented first.

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56.313 Visual Attractiveness is Leaky (5): Perceptual organization matters

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We have reported that attractiveness of an attended object is implicitly modulated by that of the task-irrelevant “ignored” object(s), using a central geometric figure with surrounding faces (Shimojo et al., VSS'10), or an attended hair (HR) and ignored face (FC) (Saegusa et al., VSS'10). In the research of face perception, it is said that the holistic perceptual process plays an important role in the attractiveness judgment (Abbas et al., 2008). If so, the attractiveness “leakage” from task-irrelevant FC to the target HR may be proportional to holistic perceptual organization between them. Here, we aimed to see how the holistic perceptual integration influences the attractiveness leakage phenomenon.

Eight FC images and 16 HR images were selected from a pre-rated set to maximize the baseline attractiveness differences. Each FC and HR were 1) combined in the natural spatial alignment and shown in upright orientation, 2) shown in a spaced, side-by-side relation to each other, or 3) combined in the natural spatial alignment, but shown in upside-down orientation. Participants were asked to judge the attractiveness of HR only in a 7-point scale.

Results showed that the baseline FC attractiveness was implicitly integrated into HR attractiveness judgment in 1), though it was not in other two conditions. Also, participants who took a shorter time to perform the task tended to show a stronger leakage effect, relative to those who took a longer time. It is consistent with the idea that the holistic perception requires shorter time to process the whole image. The results together suggest that the degree of holistic perceptual organization positively correlates with the attractiveness integration across the task-irrelevant FC and target HR images.

56.314 pSTS response to gaze reflects wider role in processing ostensive signals in multiple modalities

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Calder and Young (2005) have suggested that the greater role of posterior superior temporal sulcus (pSTS) in coding changeable (e.g., facial expression, eye gaze) versus static (e.g., identity) facial features may reflect the wider role of this region in processing social signals from multiple modalities. Indeed, previous research has shown that pSTS responds to emotional expression cues in the visual and auditory modalities (e.g., Hagan et al., 2010). Recent work (Stoyanova et al., in press) indicates that discrimination of direct gaze may be influenced by an accompanying, ostensive auditory signal with similar value (i.e., hearing one's own name). However, it is unclear whether the natural co-occurrence of these visual and auditory ostensive signals is reflected in a common neutral substrate in pSTS. To address this question, we employed a 2 x 2 factorial design with the factors of gaze direction (DIRECT/AVERTED) and name (OWN/OTHER). In a rapid event-related functional MRI study, participants viewed video clips of actors engaging in direct or averted gaze while calling out participants' own name or one of three other, syllable-matched, first names. Participants were asked to judge whether the person in the video was looking at or away from them. Face selective regions in the STS were localized in a separate functional localizer scan. Whole-brain random effects analyses revealed extensive bilateral activation in STS/STG for OWN>OTHER NAME as well as a more focussed effect of DIRECT>AVERTED GAZE in right posterior STS. In line with our hypothesis, a conjunction analysis confirmed that hearing one's own name, relative to another, and viewing direct, versus averted, gaze, engages the same region of right pSTS. Our results suggest that the role of pSTS in coding gaze direction may reflect a wider role in processing ostensive cues in different modalities.

56.315 Faces with higher contrast look younger

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The luminance difference between the eyes and mouth and the skin surrounding those features (“facial contrast”) is sexually dimorphic, with females having greater contrast (Russell 2009). Facial contrast also affects attractiveness, with females rated more attractive with increased contrast (Russell 2003). Recent work investigating full color images has found that females, but not males, are rated as more attractive when a* (green - red) contrast around the lips is increased (Stephen 2010). Here we investigated the relationship between facial contrast and age, and between facial contrast and perceived age. Using a set of carefully controlled full face color photographs of 289 women aged from 20 to 69, we measured the contrast between the eyes and the surrounding skin, the eyebrows and the surrounding skin, and the mouth and the surrounding skin, in the CIELab L* (dark - light), a* (green - red), and b* (blue - yellow) axes. There were significant decreases with age in a* (green - red) contrast around the mouth and in luminance contrast around the eyebrow and a weakly significant decrease in luminance contrast around the eye. In a separate study, subjects estimated the age of 150 of these faces. The three aspects of facial contrast that decrease with age (mouth redness, eyebrow luminance, and eye luminance) were also found to predict ratings of perceived age. Faces with greater a* contrast around the mouth, greater luminance contrast around the eyes or greater luminance contrast around the eyebrows were judged to be significantly younger. Together these findings indicate that older faces have less facial contrast than younger faces, and that facial contrast is used by observers to estimate the age of a person from their face.

56.316 Top-down Visual Attention and Gender in a Focused Listening Task

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Visual attention and patterns of eye movements may be influenced by individual characteristics, such as gender or culture, in specific stimulus and task environments. From psychology studies of social interaction, we know that gaze behavior varies between men and women when in conversation. Using eye-tracking in naturalistic settings, we found that men and women orient attention differently during conversational listening. Thirty-four subjects (15 men and 19 women) had their eyes tracked while watching and listening to twelve videotaped speakers in 84 different clips. While listening, we found that men gaze more often at the mouth ($p = 0.009$) and women at the eyes ($p = 0.028$) of the speaker. In addition, we measured the static and dynamic feature saliency according to a previously verified model of attention (Itti, 2004). When we measured the correlation (in ROC score) of each subject's eye movements to feature, we found that the fixations of men correlated more strongly with dynamic saliency ($p < 0.0001$), even at regions inside the face, i.e. the eyes ($p = 0.023$). We attribute overall gaze gender differences in social interactions to a male preference for motion and a female preference for features that are socially defined. We also propose that these gender differences arise from different integration strategies of visual cues in selecting the final target of attention. Our findings illuminate how the character of social interactions may vary by gender, and may also suggest more predictive models of visual attention that take into account individual characteristics.

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Development: Face perception

Tuesday, May 10, 3:00 - 7:00 pm

Royal Palm 6-8, Poster Boards 317 - 330

56.317 Visual scanning behaviors of 8-month-old infants facing expressive faces

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The purpose of the study was to explore visual scanning behavior of expressive faces in 8-month-old infants.

Thirty 8-month-old infants were familiarized with the neutral photograph of a female face, and then presented with expressive photographs (happy, angry, disgusted, fearful and sad) of the same female face. Eye-movements were recorded and transformed to match a prototypical face, so that to finely allow seeing which facial parts were focused according to trials and facial expressions.

The results indicated that 8-month-old infants paid attention to different facial parts according to the emotions expressed by the faces, the features associated with facial actions during emotional expressions being more specifically focused. Furthermore, the temporal course of the visual exploration indicated that, after a common pattern, the sequence of the exploration of the different facial features varied according to the facial expressions. We conclude that from 8 months, infants differently explored faces according to the expressed emotions. The implications for the study of the development of facial emotion understanding in infancy are discussed.

56.318 Mechanisms Underlying the Emergence of Expert Face and Object Representations During Infancy

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Several investigations suggest that during the first year of life, face representations become tuned to environmentally relevant faces (e.g., own-race faces) relative to environmentally irrelevant or less frequently encountered faces (e.g., other-race faces), a process called “perceptual narrowing” (Kelly et al., 2007; 2009; Pascalis, et al, 2002; 2005; Scott & Monesson, 2009; Sugita, 2008). Recently, this tuning of face representations has been found to be dependent on experience (or lack of experience) learning to match a face with an individual-level proper name during the first year of life (Scott & Monesson, 2009). However, it is unknown how early experience contributes to the neural specialization of structures underlying face processing or whether experience with objects leads to similar discrimination and neural specialization. Here, four groups of infants completed pre-training (at 6 months of age) and post-training (at 9 months) behavioral (Visual-Paired Comparison) and electrophysiological (Event-Related Potentials) assessments, which indexed face and object discrimination. Following the pre-training assessment, two groups of infants were sent home with training books of monkey faces or of objects (strollers), which were labeled at the individual level (i.e. all faces and strollers had individual names). Two more groups of infants were sent home with books of monkey faces or strollers labeled at the category level (i.e. all faces were named “monkey” or “stroller”). Infants returned at 9 months and results revealed both behavioral and electrophysiological (P1; N290; P400; Nc) differences from 6 to 9 months, and across training conditions. Only individual-level training led to behavioral maintenance (monkey faces) or facilitation (strollers) in ability to discriminate stimuli. The electrophysiological results show that infants exhibited greater ERP inversion effects for both monkey faces and strollers after individual-level, but not category-level training highlighting the importance of individual-level learning in the development of perceptual expertise for faces and objects.

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56.319 Infants' recognition of dynamic subtle facial expression

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We have already demonstrated infants' sensitivity to facial movement by measuring brain activity during infants viewing facial biological motion using NIRS (Ichikawa et al., 2010). Generally, facial movement facilitates recognition of facial expressions. While the intense expression is enough expressive to be recognized in still, the subtle expression can be recognized only when presented in motion (Ambadar et al., 2005, Bould & Morris, 2008). Although it is well-known that infants recognize static intense facial expression (Barrera & Maurer, 1981; Nelson & Ludermann, 1986, Serrano et al., 1982), it has not been examined whether infants recognize a dynamic subtle expression. The present study investigated the issue using a familiarization–novelty procedure.

To generate dynamic subtle expression, we videotaped a female performing either angry or happy facial expressions and extracted below three frames from each video clip; the first frame (neutral), the 6th frame (subtle expression), and the 13th frame (peak expression). We presented two frames of a neutral and a subtle expression alternatively as a dynamic facial expression.

3-8 month-old infants were first familiarized with a subtle expression of either anger or happiness. In the familiarization trials, infants viewed repeatedly presented the dynamic subtle expression of anger (or happiness) for 15 sec × 4 trials. Following the familiarization, infants were tested with a pair of peak expressions of familiarized anger (or happiness) and of novel happiness (or anger) expressions for 10 sec × 2 trials. We hypothesized that if infants recognize an expression from dynamic subtle expression, they would show a novelty preference for a novel expression. We found that infants could learn a subtle angry expression faster than a subtle happy expression. The results might suggest that infants recognize and learn the distinctive facial expression even in subtle expression by dynamic presentation.

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56.320 Do infant represent the facial identity in a viewpoint-invariant manner? The neural adaptation study as measured by near-infrared spectroscopy

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Neural adaptation paradigm using fMRI (fMRI-adaptation) is well established to examine the neural basis of the representation of object including face. We have applied the neural adaptation paradigm to NIRS measurement in infants and found that infants' temporal region showed an attenuated response (adaptation) during the repeated presentation of identical face (Kobayashi et al., VSS 2010). In the present study, we extended our findings of neural adaptation as measured by NIRS and showed that the temporal region of infant brain represented the facial identity in a viewpoint-invariant manner.

We measured the hemodynamic responses in the bilateral temporal region from twelve 5- to 6-month-old infants and from twelve 7- to 8-month-old infants by using NIRS (Hitachi ETG-4000 system). In each trial, infants were shown sequence of five facial images that gradually change in the viewpoint from left- to right-three-quarter view or vice versa. In the different-identity condition faces changed in the identity as well as in the viewpoint. In the same-identity condition, identity was held constant across the different views. The hemodynamic responses to the faces in both conditions were contrasted against the activation during the baseline period where various images of vegetables were shown. An attenuated response in the same-identity condition compared to the different-identity condition would suggest a viewpoint-invariant representation of facial identity in infants.

We found that the channels around T5 and T6 position in the 7- to 8-month-olds, but not 5- to 6-month-olds, showed a significant increase in the hemodynamic responses during the different-identity condition compared to the

object baseline. Further, the hemodynamic responses were significantly attenuated in the same-identity condition compared to that in the different-identity condition. Our results suggest that facial identity is represented in a viewpoint-invariant manner in 7- to 8-month-old infants.

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56.321 A longitudinal study on infants' face perception by near-infrared spectroscopy.

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Since the first study of Otsuka et al (2007), we have clarified the neural responses to face perception using near-infrared spectroscopy (NIRS) with awake infants (Nakato et al., 2009; Honda et al., 2010; Ichikawa et al., 2010; Nakato et al., 2011; Nakato et al., in press). These studies demonstrated that the right temporal cortex of infant's brain was activated during the presentation of faces and that the neural responses to face processing can be matured by the age of 7 to 8 months. However, it remains unknown how the neural mechanism related to face perception is matured during infancy.

The present study was a longitudinal investigation of the neural responses in infants aged from 3 to 8 months. All participants were measured the hemodynamic responses with NIRS at each age. The experimental stimuli were images of 5 unfamiliar female frontal and profile views as the test stimulus, and those of 5 different vegetables as the base stimulus. Measurement area for brain activity was in the bilateral temporal cortex. The experimental stimuli, the experimental procedure, and the measurement area were identical with those of Nakato et al (2009).

The result in the presentation of the frontal view showed that the number of the activated channels increased in the right temporal cortex than in the left temporal in all age groups. In addition, the activated channels were mainly located at the posterior and the inferior regions in the right temporal cortex for all age groups. These findings suggest the dominance of the right temporal cortex for face perception would emerge in infants as young as 3 months old. Our longitudinal data implies that the superiority to the neural responses in the right temporal cortex for face perception would develop at an early age during infancy.

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56.322 Jen or Sue? The influence of facial expressions on identity aftereffects in 8-year-old children

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Recent studies have suggested that adults' perception of facial identity and expression are not independent of one another. Facial expression aftereffects are dependent on facial identity in both adults (Fox & Barton, 2007) and children (Vida & Mondloch, 2009). In contrast, identity aftereffects in adult participants are independent of variation in facial expression (Fox et al., 2008), suggesting that adults' representation of facial identity is independent of expression. We examined whether identity aftereffects in 8-year-olds are modulated by changes in facial expression. In each of two experiments, children (n = 30) were shown an adapting face followed by a morphed blend between two identities. Adaptation significantly biased children's perception of the test identity away from the adapting identity, an effect that was independent of whether the morphed and adapting identities had the same or different emotional expressions. This indicates that, like adults, 8-year-olds process facial identity independent of expression. However, to be included in the above adaptation analyses, children were required to correctly categorize two facial identities at 100% identity strength and then at 80 and 90% identity strength across variations in expression. Approximately 33% of children were unable to pass training, despite the use of more distinctive faces and a more elaborate training procedure in Experiment 2. This suggests that there are individual differences in the extent to which 8-year-olds process identity independently of expression. In Experiment 3, we investigated these individual differences using a Garner interference task. Children categorized facial identities when expression was held constant (control trials) and when expression varied across trials (orthogonal trials). To date, data (n = 9) indicate that,

unlike adults (Baudouin et al., 2008), 8-year-olds' reaction times are longer on orthogonal than control trials. Children's ability to process identity may be transitioning to an adult-like pattern at 8 years of age.

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56.323 The attractiveness of facial averageness: A comparison of adults and children

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Adults rate averaged faces with feature shapes, sizes, and locations approximating the population mean as more attractive than most individual faces (e.g., Langlois & Rogmann, 1990). We are examining developmental changes in the influence of averageness on judgments of attractiveness by showing adults and children pairs of individual faces, in which one face was transformed 50% towards average, while the other face was transformed 50% away from average. In separate blocks of 16 trials, participants judged pairs of adult female faces, pairs of girls' faces, and pairs of boys' faces, and selected which face in each pair they found more attractive. Before testing, faces were made symmetrical and were rated as looking natural by adult judges (M score out of 5 = 3 for all three face sets).

Adults (n = 36) rated the more average faces as more attractive than the less average faces for all three types of faces (M choice of more average > .92 for women's, girls', and boys' faces; all ps <.001).

Five-year-olds (n=36) rated the more average faces as more attractive than the less average corresponding faces (all ps <.001). The strength of child preferences, however, was significantly weaker than that of adults (M choice of more average > .74; main effect of age, p <.001). Results will be compared to those from ongoing tests of older children.

The results indicate that the influence of averageness increases between age 5 and adulthood. The changes may reflect the refinement of an average face prototype as the child is exposed to more faces, increased sensitivity to configural and subtle featural cues in the faces experienced, and/or the greater salience of attractiveness after puberty.

56.324 Look me in the eye: A comparison of fine-grained sensitivity to eye contact between 8-year-olds and adults

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Adults perceive that a face is making eye contact with them when the actual fixation position is within a range of 2-4.5° to either side of the bridge of their nose (the cone of gaze) (Gamer & Hecht, 2007). Children as old as 11 years are less accurate than adults at judging whether someone is looking at their eyes or at another part of their face (Lord, 1974). Here, we developed a child-friendly procedure to compare the width and centering of the cone of gaze between 8-year-olds and adults (n=18/group). Participants sat in front of a computer monitor on which they saw faces fixating the center of the camera lens and a series of surrounding positions (separated by 1.6°) to the left/right (horizontal blocks) or upward/downward (vertical blocks). Participants performed a 3AFC task in which they judged whether the model's gaze on each trial was direct, averted left (or up in vertical blocks), or averted right (or down). For each participant and block type, we fit a psychometric function to the proportion of each response type and calculated the width of the cone of gaze from the crossover points between the fitted 'direct' function and the two other functions. The cone was wider in 8-year-olds (M=7.19°) than adults (M=6.23°), p<.02, and wider for the vertical (M=7.62°) than the horizontal (M=5.80°) axis, p<.001. In both age groups, the cones were centered around exactly direct gaze, whether the centering of each cone was measured from the maximum of the fitted 'direct' function or the midpoint between the edges of the cone, with no difference between ages or directions, ps>.05. The results indicate for the first time that 8-year-olds are almost as good as adults in detecting deviations from direct gaze.

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56.325 **Developmental changes in encoding and the capacity to process face information.**

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The question of whether there are developmental changes in the ability to encode and the capacity to process face information is the subject of ongoing debate. While a subset of studies in the developmental face perception literature suggests these aspects of face perception are mature early in childhood, other studies report age-related improvements on face perception tasks that have been interpreted as developmental changes in these abilities. Three alternative explanations suggest improvements in performance on face perception tasks could be the result of developmental changes in: (a) encoding face information (b) the capacity to process face information (c) quantitative rather than qualitative improvements in performance on face perception tasks. The present work used powerful theoretical frameworks capable of testing these three alternative hypotheses in a sample of children and adults (ages 6 - 22). First, theoretical constructs and measures from general recognition theory (GRT; Ashby & Townsend, 1986), a multidimensional generalization of unidimensional signal detection analyses, were used to test for developmental changes in holistic encoding across two tasks: (a) a composite face task (b) an inversion task. Critically, these experiments were within-subjects and stimuli were constructed from the same faces for both experiments. Second, a subset of the participants completed additional experiments in order to assess their capacity to process face information. In these experiments processing capacity was theoretically defined and measured using theoretical constructs and measures provided by systems factorial technology (SFT; Townsend & Nozawa, 1995) and the Cox Proportional Hazards Model (Cox, 1972). Overall, the results of these experiments provide strong within-subjects evidence of quantitative rather than qualitative changes in the ability to encode face information across development. In addition, developmental changes in the capacity to process face information were assessed within-subjects and interpreted with respect to the ability to encode face information.

56.326 **The effect of gaze direction on 3D face learning in infants**

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Our recent study showed that six- to eight-month-old infants could learn the three-dimensional face in static presentation of different viewpoint images but not in the presentation of sequentially rotating images (Yamashita et al., VSS 2010). In this experiment, we presented rotating face with gaze, in the condition participants perceived the averted gaze according to face rotating. It should make a difficulty in face learning especially for infants. The direction another person's eyes are looking tells us the direction towards which the person is paying his or her attention. Previous study shows that response time of adult participants for detection of the gaze direction is faster when the eyes and the head were congruently oriented, than when they were incongruently oriented (Seyama et al., 2005). Here we investigated developmental influence of the gaze direction using the artificially-produced faces. In our experiment, we presented the artificially-produced in rotating face whose face and the gazes were congruent orientation or incongruent orientation. In the former condition we could perceive rotating face with averted gaze, and in the latter condition we could perceive the rotating face with direct gaze. For both condition, sixty-one sequential images of each face were created by rotating an axis perpendicular to the visual axis connecting the viewer's eyes and the face from frontal view to plus-minus 30 deg. Six- to eight-month-old infants participated in the present study and compared their performance in two conditions. Results showed that only 8-month-old infants learned the face in incongruent but not in congruent condition. This result suggests that the gaze direction may affect the 3D face learning.

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56.327 **Six-month-old infants perceive the concave face illusion as convex.**

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The visual system must employ assumptions, or constraints, to interpret pictorial (static monocular) displays. For example, for the depth cue of relative size to be effective, adults use an assumption that two objects are similar in size in perceiving the retinally larger one as closer. Our goal is to investigate if and when infants, like adults, use similar assumptions to perceive 3-D layout. Last year at VSS, we reported that six-month-old infants use line junctions to perceive a concave shape as convex when only static monocular information is available. In the present study, we investigated whether infants, like adults, use the assumption that faces are convex. Specifically, we used Richard Gregory's concave face illusion to examine if infants use prior knowledge about the 3-D layout of faces to direct their reaching to the apparently closest part of the display (the nose). Methods: Using a within-subjects design, we presented six-month-old infants (n=11) with Gregory's concave face illusion and observed the trajectory of infants' reaching behavior under monocular and binocular viewing conditions. Reaching behavior was scored by a blind observer. Results: Infants reached more often to the center of the display in the monocular condition (67%) than in the binocular condition (12%, $p=0.001$). These results indicate that infants perceived the display as convex under monocular viewing conditions and as concave when viewing the display with two eyes. In addition, in the monocular condition, some infants attempted to grasp the nose of the face. Discussion: These findings suggest that experience with the concave nature of faces may influence how infants respond to this illusion. This provides further evidence that infants use assumptions to perceive the 3-D structure of the environment.

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56.328 **Infant and Adult Preferences for Upright Faces are Driven More by High, Than Low, Spatial Frequencies**

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Background: It has been suggested that infants rely on low spatial frequency (SF) mechanisms for face processing. Using stimuli that were equated for detectability, we recently reported that 4-month old infants' larger upright preference for faces than objects was greater for "high" than "low" SF-filtered stimuli (Dobkins & Sampath, VSS 2010). Here, we asked if this pattern in 4-month-olds is adult-like by testing adults in the same paradigm. Methods: Adults (n=5) were presented with an upright stimulus and its inverted image on the left and right side of a monitor, respectively (or vice versa). The stimulus was either a face or an object (the latter being a stroller). Using forced choice preferential looking, wherein the adult observed the stimuli passively, we determined the percentage of trials the adult looked preferentially at the upright stimulus. Six conditions were presented: 2 stimulus types (faces vs. objects) x 2 cutoff SFs (1 & 2 c/deg) x 2 SF filters (1 c/deg cutoff: "low" <0.8 c/deg vs. "high" > 0.1.2 c/deg; 2 c/deg cutoff: "low" <1.6 c/deg vs. "high" > 2.4 c/deg). In our previous study of 4-month-old infants, the cutoff SF was 0.4 c/deg. For both infants and adults, all stimuli were presented at 3.3x contrast threshold. Results: For cutoffs of both 1 and 2 c/deg, adults' larger upright preference for faces than objects was greater for "high" (1 and 2 cpd cutoff, $p = 0.02$ and 0.005 , respectively) than "low" (1 and 2 cpd cutoff, $p = \text{NS}$ and 0.02 , respectively) SF-filtered stimuli. Conclusions: In adults and 4-month old infants, the mechanisms underlying upright face preferences appear to be preferentially selective for high SFs. This indicates that the mechanisms for face processing are fairly mature at 4-months of age.

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56.329 **The Organization of Young Children's Face Space: Complete Transfer of Aftereffects from Own- to Other-Race Faces in 5-Year-Olds**

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Adults (Jaquet et al., 2008) and 8-year-olds (Short et al., 2011) possess race-specific face prototypes; after viewing Caucasian and Chinese faces distorted in opposite directions, their attractiveness ratings shift in opposite

directions (opposing aftereffects). We recently demonstrated that 5-year-old Caucasian children with minimal exposure to Chinese faces exhibit evidence for race-specific face prototypes; however, opposing aftereffects in 5-year-olds are driven largely by simple aftereffects for Caucasian faces (Short et al., 2011). These results may indicate that Caucasian 5-year-olds process Chinese faces as individual exemplars; alternatively 5-year-olds' emerging Chinese prototype may be weakly defined, resulting in their referencing both a Caucasian and a Chinese prototype when processing Chinese faces. We tested the latter hypothesis by measuring transfer of aftereffects in 5-year-old children. Adults show partial transfer of aftereffects from Caucasian to Chinese faces, indicating that they possess separable but not distinct representations of Caucasian and Chinese faces (Jaquet et al., 2008). If 5-year-olds reference a Caucasian prototype when encoding Chinese faces, they should show complete transfer of aftereffects. Five-year-old Caucasian children ($n=24$) were adapted to compressed Caucasian faces; both before and after adaptation, they judged the attractiveness of distorted Caucasian and Chinese faces. Aftereffects were no larger for Caucasian faces than for Chinese faces, $p > .30$. This complete transfer of aftereffects suggests that in 5-year-olds, the Caucasian and Chinese prototypes are largely overlapping and that Chinese faces are not processed as individual exemplars. In a follow-up study, we are examining whether Caucasian 5-year-olds show simple aftereffects for Chinese faces and the extent to which these aftereffects generalize to Caucasian faces. This work provides novel insights into the organization of young children's face space and the potential role of experience in the development of prototype(s) for other-race faces.

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56.330 Developmental Changes in the Strength of Identity-Specific Expression Aftereffects

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Face adaptation can be used to explore the relationship between identity and expression representations. Robust facial expression aftereffects are obtained when face identity is held constant across adapting and test stimuli, but changes in identity diminish the strength of the effect (Fox & Barton, 2007). Similar effects are seen in children with 7-year-olds demonstrating adult-like aftereffects for happy-sad expressions (Vida & Mondloch, 2009). This suggests children use identity as a context for reading expressions. Individual differences in expression geometry point to the potential benefits of calibrating the perceptual system to read emotional expressions in individual faces. Although traditional models posit separate processing streams for emotion and identity, current models also include connections and/or coding redundancies (e.g., residual information for identity within the expression code.) If adaptation effects reflect moment-to-moment recalibrations in the perceptual system, (i.e., design features that help to optimize performance), identity-specific expression aftereffects (which reflect a recalibration for a specific identity) should grow stronger with age. We used a condensed (50 trial) version of Fox and Barton's task (2007) to explore changes in the relative strength of identity-specific expression aftereffects in school age children. Children ($n=47$; ages= 5-12 years) were presented with adapting and test images that were different sizes to reduce the role that low-level features play in the strength of the same person adaptation effect. Neutral (no-adapt) trials were mixed within the block to assess response bias. A measure of "person-specific" adaptation was computed by comparing performance on same-person and different-person trials for happy and sad adaptors. Consistent with our hypothesis, the person specificity of the adaptation effect was significantly correlated with age ($r=.396$, $p<.01$, for sad adapt trials). This age-related increase in adaptation strength suggests that during middle childhood the perceptual system becomes increasingly fine tuned to how emotions are expressed in individual faces.

Visual search: Natural scenes and practical tasks

Tuesday, May 10, 3:00 - 7:00 pm

Orchid Ballroom, Poster Boards 401 - 411

56.401 Scene-based Contextual Cueing in the Rhesus Macaque

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The neurophysiology that underlies the guidance of attention during search through naturalistic scenes remains largely unexplored. In order to understand how scene identification leads to the prioritization of certain regions of space, we have developed an animal analogue of scene-based contextual cueing in the monkey so that we might conduct physiological experiments.

Our task was adapted from the contextual cueing task of Brockmole and Henderson (2006). The monkey must search for a semi-transparent object embedded in a real-world scene. The monkey has previous experience classifying these objects into one of two arbitrary categories by pressing response buttons. In half of the scenes (non-predictive condition), objects appeared randomly in one of eight locations. In the other half of the scenes (predictive condition), scene identity cued the location of the object through consistent scene-location pairings. Along with manual reaction time, we also tracked the monkey's eye-position in order to examine how the monkey searched through each scene and how many saccades it took to locate the target.

As in humans, the monkey showed a benefit when executing searches through repeated scenes across multiple sessions, demonstrating sensitivity to scene familiarity. The monkey also showed a significant reaction time benefit when searching through predictive scenes when compared to non-predictive scenes, demonstrating scene contextual cueing. Similar to the associations formed by human participants in Chun & Jiang (2003), these scene-location associations were stable after a week-long hiatus, indicating the long-term nature of the associations. Finally, we conducted target-absent tests during which we monitored eye-movements. In these tests, the monkey saccaded to the cued location in an average of less than two saccades and did so on greater than 90% of trials.

These results demonstrate scene-based contextual cueing in the macaque, showing promise as a method for uncovering the physiological basis for attentional guidance during active search.

56.402 Costs of Switching Scene Category in Real-World Visual Search

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Real-world visual search is heavily dependent on context, and experienced searchers use their knowledge of scenes to facilitate search. While it is known that visual search is facilitated by repetition of a specific scene, scenes in the real world often differ across searches. To compensate for this, people may employ search strategies that vary with contextual categories as well as for a specific scene context. If so, switching from a familiar scene category to a new category may exact a search cost. In other words, if search for birds in urban scenes has become proficient, birds in a forest scene may initially be difficult to find. Several predictions follow from this intuition: (1) Repeated search in a series of novel but categorically similar real-world scenes should facilitate visual search, and (2) A switch to a different real-world scene category should cause a drop in search efficiency. To test these predictions, we had 30 participants search for 20 different examples of birds in 40 different scenes of three different categories: urban, forest, or indoor, with 3 blocks of search trials blocked by category. We observed a significant cost of switching scene categories in search efficiency when search had become proficient in the prior category. Furthermore, search was particularly inefficient when the target bird appeared in the bottom quarter of the scene, consistent with prior results suggesting that knowledge of real-world target probability influences expectations about target locations. The cost of lower scene locations on search was reduced for the indoor scenes, suggesting that knowledge of scene context influences location expecta-

tions in visual search. These results suggest that categorical scene context and prior knowledge of target location likelihood interact to affect search strategy and efficiency.

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56.403 **The Evolution of Clutter Effects in Visual Search**

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Visual clutter holds great promise as a surrogate measure of set size effects in scenes, but just as all search objects are not equally distracting, clutter too may take different forms. We compared the effects of subjective clutter (determined by independent raters) and objective clutter (as quantified by edge count) on visual search using “evolving” scenes that varied systematically in clutter, yet maintained their semantic continuity. Observers searched for a visually-previewed target building in rural, suburban, and urban city scenes created using the game SimCity. Stimuli were 30 screenshots obtained for each scene type as the city evolved over time (e.g., urban scene-1 was a field with some roads; urban scene-30 was a bustling metropolis). Both subjective and objective clutter estimates were highest for urban scenes, intermediate for suburban scenes, and lowest for rural scenes. These identical relationships characterized the effect of clutter on RTs and search guidance (measured by scanpath ratio); RTs and guidance were fastest/strongest for rural scenes, slower/weaker for suburban scenes, and slowest/weakest for urban scenes. Importantly, subjective and objective within-city clutter estimates also increased as each city matured, but the effects of these clutter changes on search depended on the type of estimate. RTs and guidance correlated highly with subjective within-city clutter (as clutter increased, RTs were longer and gaze followed a less direct route to the target; R2 ranging from .52-.70), but within-city correlations between objective clutter and RTs (R2 .10-.31) and guidance (R2 .34-.40) were weaker. The fact that subjective estimates better predicted search than objective estimates suggests that within-city clutter may not be explained by low-level feature congestion alone; conceptual congestion (e.g., the number of different types of buildings in our scenes), part of the subjective clutter measure, may also be important in determining the effects of clutter on search.

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56.404 **Redundancy gains using real-world objects**

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It is well established that manual reaction times (MRTs) to the onset of a display depicting two simple objects are faster than a corresponding one-object display (e.g., Savazzi & Marzi, 2008), and that a similar benefit exists in visual search for feature-targets defined by two dimensions rather than one (e.g., Krummenacher et al., 2001). We investigated this phenomenon, referred to as redundancy gain (Miller, 1982), in the context of visually complex real-world objects and using both MRT and eye movement measures. Experiment 1 asked whether redundancy gains can be found for object parts. Search displays consisted of eight partial or whole teddy bears, one of which differed from the others in its number of parts. Participants were instructed to press a button when fixating the odd target in the search display, where oddness was defined by either one or two parts differing from the distractors. Redundancy gains were observed both in MRTs and in search guidance (time to target fixation), but not in verification time (difference between MRT and fixation time-to-target), suggesting that parts can be processed early by the visual system much like basic visual dimensions in a search task. Experiment 2 asked whether redundancy gains can be found across object category. Participants made a speeded response to the onset of a display containing either one or two objects. Two-object displays consisted of either two instances of the same object, two different objects of the same category, or two objects from different categories. MRTs were generally faster for all three two-object display conditions, but redundancy gains were unaffected by object category. This suggests that categorical information is not accumulated in parallel for the purpose of display onset detection. Redundancy gains can thus be found for real-world objects, bringing a new methodological tool to the study of object perception.

Acknowledgement: Swiss National Science

56.405 **Is there inter-trial priming of popout with pictures of real stimuli?**

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How fast are we to detect a particular make of car when shortly before we spotted a different-colored car of the same make or a same-colored car of a different make? Would another category of vehicle (a plane) affect detection of a car? Found and Müller (1996) investigated feature- and dimension-based inter-trial effects in ‘priming of pop-out’ (Maljkovic & Nakayama, 1994) visual-search tasks for simple objects (red vertical or green tilted bar target among green vertical distractors). Analyzing for the cross-trial repetition versus change effects, they found a significant effect only for target dimension changes (e.g., from color to orientation), but not for feature changes (e.g., from red to blue). Their results suggest that inter-trial priming is primarily dimension-based. The present study was designed to investigate the pattern of inter-trial effects with pictures of real stimuli. Observers had to search for a target that was “not a fruit” (car, plane, or bird) among fruit distractors. Four different types of inter-trial relations between targets on successive target-present trials were examined. If the target on trial N was a car of a particular make, the target on trial N-1 could be the same car (identical object), another make (same category), a plane (same superordinate category: ‘vehicle’), or a bird (different superordinate category: ‘animal’). Change costs were calculated by comparing RTs for the identical object condition minus RTs for the three different change conditions (same category, same superordinate category, different superordinate category). The largest costs were observed if the superordinate category changed, smaller change costs were found for category changes within the superordinate category; by contrast, no costs occurred if targets changed within categories. Thus, category- and feature-changes in complex objects seem to produce similar inter-trial effects to dimension- and feature-changes in simple objects.

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56.406 **Depth and Size Information Reduce Effective Set Size for Visual Search in Real-World Scenes**

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Identification of classic attributes guiding search is based on experiments using unstructured displays. These attributes do not explain the efficiency of search in real scenes. We propose that “depth guidance” can massively reduce the effective set size in real scenes. Fast, non-selective processes are known to provide information about spatial layout and about proto-objects. Given approximate distances and object sizes in the image, only a very few proto-objects can possibly be the current target. To test, we had participants draw boxes on 200 real-world images (indoor and outdoor) indicating multiple possible locations and sizes for target objects (cats, cups, and people) that were not in the images. In the main experiment, one box was picked as the target. Other box locations were chosen as distractors and the boxes resized to match the target’s image size. Thus, if observers were looking for cats, only one box would be the right size to just hide the cat. On each trial, observers used as few mouseclicks as possible to identify that box. At chance performance, the slope of the function relating guesses to set size is 0.5. On average, the guesses x set size slope was 0.30. If dots replaced boxes, eliminating the possibility of depth guidance, the slope increased to 0.52 (chance). Our depth guidance slope estimate of 0.30 is too steep because some distractors were chosen from boxes placed at the roughly the same distance as the target object, making those boxes of an appropriate size. These are scored as distractors but could be targets. An additional experiment estimated that this occurred on 42% of trials. Correcting the slope for this factor yields an estimated slope of 0.19. This shallow slope suggests that depth guidance effectively reduces the number of candidate targets in real scenes by directing attention to size-appropriate objects.

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56.407 Searching Simulated Lungs in 3D with Stereoscopic Volume Rendering

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A modern Computed Tomography (CT) scan can yield 700 slices at 512x512 pixel resolution. Radiologists search through vast amounts of data looking for subtle visual targets by scrolling back and forth through such stacks of images. Can we make search less difficult and time consuming? We compared stereoscopic volume rendering to traditional slice-by-slice viewing. Our new software uses GPU processors that enable real-time rotation of volume renderings. We created artificial stimuli designed to emulate challenges of real medical search tasks. Targets and distractors were placed randomly in a 200x200x600 volume of 1/f³ noise. Images were viewed with a Planar polarized mirror system where 200x200 pixels subtended 8 deg of visual angle. Distractors were randomly oriented ellipsoids with two axes of length 15 and one of length 20 voxels. Observers searched for an egg-shaped target, created by fusing half of a randomly oriented ellipsoid with a sphere of diameter 15 voxels. Eggs and ellipsoids were twice the maximum intensity of the noise and blended into the background at their edges. We tested observers' ability to find the egg among ellipsoids in two conditions. The slice-by-slice condition allowed observers to scroll back and forth through 600 images, one at a time. In the stereo condition, 50-slice rendered stereo 'slabs' could be sampled, rotated, and viewed under user control throughout the data volume. Stereo slabs were rendered by maximum intensity perspective projection, whereby, when multiple voxels project to a single view plane pixel, only the highest intensity value gets drawn. In every trial observers searched for one target among seven distractors and responded with a mouseclick on the suspected target. Stereo viewing was more accurate (98 vs 48 percent correct) and faster (42 vs 84 sec per trial mean) than "stack mode". These would be dramatic improvements if they generalize to clinical settings.

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56.408 When and why does Computer Aided Detection (CAD) interfere with visual search?

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The detection of tumors in x-ray images is an important task for radiologists in the battle against cancer. Computer aided detection (CAD) programs are increasingly deployed in the clinic, but these programs are controversial. While most studies show better performance with the help of a CAD system, several studies have suggested that CAD does not increase hits in clinical settings (Gur et al., 2004, Brem & Schoonjans, 2001), while others have shown that CAD increases false alarm rate (Fenton et al., 2007). A common fear is that CAD users may become overly reliant on CAD marks and will miss unmarked cancers. The small amount of data supporting this concern is largely based on behavioral outcomes. In the current study, we monitored eye-position to gain insight into this question. Since radiologists have limited availability as observers, we created a laboratory analog task that could be used with non-experts. Observers searched for semi-transparent Ts amongst Ls. The background was 1/F noise, used as an approximation of visual texture generated by imaging human tissue. Each observer completed 200 trials: one block with the help of a CAD system and one block unassisted. CAD marked 75% of Ts and 10% of Ls. Results: Without CAD, hit rate was 83%. On CAD trials, hit rate was significantly higher if the target was marked (97%, p<.001) but significantly lower if it was not marked (58%, p<.0001). Target fixation rate was comparable for missed targets in CAD and non-CAD conditions. However, dwell time on distractors was lower with CAD. In this task, at least, the increased miss rate for unmarked targets seems to reflect a failure to adequately consider potential targets, rather than a failure to search for and locate them.

Acknowledgement: Ey017001

56.409 Why don't Computer Aided Detection (CAD) algorithms help experts as much as they should?

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Radiologists are extremely good at difficult medical visual search tasks, but far from perfect. Computer Aided Detection (CAD) programs have been developed to improve radiologists' performance. However, though the CAD systems perform well, adding CAD does not produce the gains in radiologist performance that one would expect. In some studies, CAD does not improve performance (d') (e.g. Gur et al., 2004). In others, there is evidence for improvement, but the effects are surprisingly small (e.g. Birdwell et al., 2005). Traditional CAD systems mark areas that exceed some threshold: One point on the CAD ROC, representing a specific tradeoff between CAD misses and false alarms. Locations generating very high CAD signals produce the same marks as near-threshold locations. Suppose the CAD signal reflected the computer's confidence. Would this analog CAD signal improve observers' performance more than traditional binary (on/off) signals? We created stimuli defined by two noisy signals: a visible color signal (targets are redder) and an "invisible" signal that informed our CAD system. Observers were tested in four blocks: visible signal alone, visible plus binary CAD, visible plus analog CAD, or analog CAD alone. Set size was one in Experiment 1. Binary CAD was slightly but not significantly better than no CAD. However, analog CAD performed significantly better (p<.02). In Experiment 2, observers searched for a target amongst six items. Both traditional binary and our analog CAD significantly improved performance (p<.01) and again we found that analog CAD performance was better than binary CAD. There are sizable individual differences in performance on this task and other factors are important in the efficacy of CAD in clinical settings. Nevertheless, our data suggest that the form of the CAD signal can directly influence performance and that analog CAD signals may allow the computer to be more helpful to the searcher.

Acknowledgement: Ey017001

56.410 What Events are Critical for a Lifeguard to Monitor? An Examination of Responses by Instructors, Lifeguards, and Non-Lifeguards

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A lifeguard's job is primarily visual surveillance, although the bulk of training focuses on rescue technique and first aid. Lifeguards are taught to search for certain behaviors that are indicators of drowning, but are also encouraged to prevent drowning. These target features are often ill-defined in the training manuals, and are present in non-distressed swimmers, so it is unclear if lifeguards are using these features to guide their search. In this study, lifeguard instructors (N = 10, median years since lifeguard training = 11.5, range = 3 - 41), lifeguards (N=10, median years since lifeguard training = 2.5, range = 3 mo - 5 yrs), lifeguards-in-training (N = 9, tested before surveillance training and again at the end of the course), and non-lifeguards (N = 20) watched 20 videos (two minutes each) of normal swimming activity at a variety of Connecticut locations (ocean beach, lake, indoor pool) and clicked on events they thought were critical for a lifeguard to monitor, and explained why. Over 300 events and general comments were provided by the participants, mostly related to horseplay (standing on or jumping off another's shoulders, excessive splashing), water depth (being too far from shore), and submersion. The lifeguard instructors provided 196 events and comments, but no single one was identified by all instructors. Only 14 events were identified by at least seven instructors, and these events were identified by the other participants, but not systematically by group. In fact, non-lifeguards often reported similar events as lifeguards. The top 40 events (identified by the most people) were analyzed further to determine whether instructors and lifeguards (on average) identified events faster than non-lifeguards and those in training. Preliminary results suggest that identification was faster with the lifeguards-in-training at posttest, but there were no differences between the other groups. This work reinforces the value of using visual cognition methods to examine and solve practical problems outside the laboratory.

56.411 Accuracy in dual-target visual search is hindered by anticipatory anxiety

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Laboratory-based visual searches provide a powerful tool for revealing the nature of cognitive processes and informing visual searches conducted outside of the lab. However, whereas professional searches, such as baggage screening, military searches, and radiological examinations, are often conducted in high-pressure environments and can contain multiple visual targets, laboratory searches tend to be conducted in emotionally-neutral settings and with only one possible target per display. These discrepancies potentially diminish the benefits of laboratory-based searches and leave important questions unanswered. To better emulate high-pressure search conditions, we presented searchers with visual arrays that could contain 0-2 targets while inducing anticipatory anxiety via a threat of shock paradigm. In the threat of shock condition, participants occasionally received an unpredictable (aversive, but not painful) electrical shock to the wrist, unrelated to their performance. In the control condition, participants occasionally heard an innocuous tone, also unrelated to performance. Each participant completed 28 10-trial blocks (alternating between conditions), with electrical stimulation occurring pseudo-randomly on four and a tone occurring on four. To focus on anticipation, blocks that contained a shock or tone were not analyzed. Under anticipatory anxiety (confirmed by increased skin conductance levels), participants' dual-target search accuracy was negatively impacted, but single-target accuracy and time-on-task were unaffected; that is, overall performance was relatively stable, except for their ability to detect a second target in an array after having found a first. Further, this effect was modulated by individual differences in state anxiety prior to testing: participants with higher state anxiety scores had higher autonomic arousal overall and thus showed a reduced relative autonomic response to the threat of shock. Likewise, they had a reduced difference in dual-target accuracy between conditions. These findings reveal key impacts on cognitive processes beyond what standard visual search tasks show, and simultaneously inform cognitive theory and real-world searches.

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Visual search: Neural mechanisms

Tuesday, May 10, 3:00 - 7:00 pm

Orchid Ballroom, Poster Boards 412 - 418

56.412 TMS reveals attentional feedback to area V1 during serial visual search

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Visual search tasks have been used to understand how, where and when attention influences visual processing. Current theories posit that when an observer searches for a target among an array of distractors, low-level processes first decompose the visual scene into elementary features, then a higher-level process involving a "saliency map" selects a candidate location to focus attentional resources. For a parallel (or "pop-out") task, this location is always the target; but for a serial (or "difficult") task, the system may cycle on a few distractors before finally focusing on the target. This implies that attentional effects upon early visual areas, involving feedback from higher areas, should be visible at longer latencies during serial rather than parallel visual search. A previous study (Juan & Walsh, 2003) had used Transcranial Magnetic Stimulation (TMS) to support this conclusion; however, only a few post-stimulus delays were compared, and no control TMS location was used. Here we applied TMS double-pulses (sub-threshold) to induce a transient inhibition of area V1 at every post-stimulus delay between 100ms and 500ms (50ms steps). The search array was presented either at the location affected by the TMS pulses (previously identified by applying several pulses at supra-threshold intensity to induce phosphene perception), or in the opposite hemifield which served as a retinotopically-defined control location. Two search tasks (n=12) were used: a parallel (finding the symbol + among Ls) and a serial one (T among Ls). TMS specifically impaired the serial, but not the parallel search. We highlight an involvement of V1 in serial search 300 ms after the onset; conversely V1

did not contribute to parallel search at delays beyond 100 ms. This study supports the idea that serial search differs from parallel search by the presence of additional cycles of a select-and-focus iterative loop between V1 and higher-level areas.

Acknowledgement: This research was supported by a EURYI grant and an ANR grant JCJC06-154 to RV.

56.413 The role of V5/MT in visual search amongst moving items: new evidence from transcranial magnetic stimulation

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Mechanisms for selective attention are vital for perception of motion. It has long been known that the right posterior parietal cortex (PPC) plays a role in a certain visual search tasks, while a human motion area V5 is involved in tasks processing attention to motion. Several theories have been proposed for the role of V5 in relation to visual search. The influential 'motion filter' hypothesis (McLeod et al., 1988) states that area V5 acts as a motion filter, where moving items are represented strongly, and static items are represented only weakly. We explored the role of V5 as a motion filter by investigating visual search of constantly moving items with transcranial magnetic stimulation (rTMS). Specifically, we compared the effect of stimulating the right V5 and right PPC in normal participants while searching for a moving T either amongst moving L's (feature search) or amongst moving O's and static T's (conjunction search). The task was to indicate the pointing direction of the moving T. If the V5 acts as a motion filter, as proposed, then rTMS should generate impairment on a conjunction search. If the PPC is crucially implicated in directing visual spatial attention (Mesulam, 1981; Bisley and Goldberg, 2003) then stimulation should impact visual search performance on both tasks. We found that stimulation of V5/MT decreased search performance in the feature search. Search slopes in the T amongst O's task were not affected. PPC stimulation did not disrupt processing of either conjunction, or feature search. We demonstrate novel and striking evidence that area V5 is causally involved in the processing of search displays where all items are moving, arguing against its role as a motion filter. Our findings challenge the conventional interpretation of the role of V5 in conjunction search and spatial attention.

Acknowledgement: Supported by the Experimental Psychology Society (EPS)

56.414 Attentional priority of saccade goal selection during visual search is represented by the relative normalized responses of lateral intraparietal neurons

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The probability of selecting a visual stimulus as the goal of an eye movement during efficient visual search depends on the value of that stimulus in the context of the task. We have previously shown that activity in the lateral intraparietal area (LIP) represents a priority map, the activity of which can explain efficient search. It has been suggested that activity in LIP is correlated with the likelihood of reward, set size or global computations of relative reward value during visual decision making task. However, it is not clear how values for saccade goal selection are prioritized while foraging through a cluttered visual scene. We trained two animals to perform a visual foraging task in which they were free to search through potential targets and distractors to identify the target that was loaded with reward. To get the reward they had to fixate the loaded target for 500 ms. The number of targets and distractors varied in each trial. In half of the trials the total number of objects was 10 but the number of potential targets varied among 3, 5 or 7. In the other half of the trials the number of potential targets was 3 but the number of objects varied among 3, 5 or 7. Stimuli were spaced such that when looking at one stimulus, another was in the LIP neuron's receptive field. We find that the probability of making a saccade to a target or a distractor can be precisely predicted as a function of the number of targets and distractors. The predicted function can be used to calculate the trial-by-trial attentional priority, which is highly correlated to the weighted normalized activity of LIP neurons. We suggest that the activity of LIP neurons represents the attentional priority of the goal in context of the task.

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56.415 Neural activity in the parietal priority map explains saccadic reaction times.

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Reaction times (RTs) are commonly used to infer the attentional state of the brain, however a direct neural correlate for RTs under these conditions is unknown, although there is growing evidence that neuronal activity can explain RTs in decision making tasks. We propose that reaction times directly represent the state of activity on a priority map, using inhibition of return (IOR) as an exemplar. We have previously shown that the neural responses in LIP play an important role in guiding efficient visual search by suppressing the responses to an inspected target. We suggested that this suppression is a neurophysiological correlate of IOR; by suppressing activity on the map, gaze should not return to items that have already been examined. In this study, we aimed to show that this activity can explain the slowing of RTs at a pre-attended location. We trained two animals to perform a visual foraging task in which they had to find a reward loaded T among 5Ts and 5 distractors. On 50 % of trials the search display disappeared and a probe flashed immediately at one of 10 locations. The animals' RTs to the probe were analyzed depending on the class of the object and whether it had been looked at prior to the probe appearing. We found that RTs were quickest to a T that had not been examined and significantly slower to Ts that had been looked at and distractors. We found that the results could be explained as a function of the neural activity in LIP based on a rise to threshold model incorporating neural adaptation. We conclude that RTs are a direct representation of activity in a priority map and that, under constrained conditions, RTs correlate with attention because priority maps are used to allocate attention.

Acknowledgement: NIH Grant EY019273, The McKnight Foundation

56.416 fMRI evidence for the neural representation of target detection in natural scenes

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Studies in humans and monkeys indicate that regions of parietal cortex are engaged in attention and target detection (Corbetta 2000, Shulman et al. 2003), the accumulation of evidence (Bisley & Goldberg, 2003, Gold & Shadlen, 2007), and choice confidence (Kiani & Shadlen, 2009). However, little is known about the role of these parietal mechanisms in visual search of real scenes. Here we use fMRI and multivariate pattern classifiers to show that several high-order areas can reliably predict the presence/absence of arbitrary target objects in natural scenes. Eleven observers searched for a target object in a natural scene (250 ms) that was specified by a cue word (400 ms) presented prior to the search display. Observers rated target presence/absence using a 10-point confidence rating scale. A multivariate pattern classifier was used to predict the presence/absence of target objects within natural scenes from single-trial fMRI data acquired during the task in regions identified by standard localizers. Classifier performance indicated that while both anterior IPS and FEF predicted target object presence/absence, aIPS was the best predictor. In addition, the correlation between image-specific choices of human observers and those predicted by the classifier was highest in aIPS ($r = 0.36$, $p < 0.001$) and FEF ($r = 0.30$, $p < 0.001$). Classifier decision variables extracted using single-trial aIPS responses also resulted in the highest positive correlation between behavioral confidence ratings and the neural decision variables. We provide evidence that two areas within the frontoparietal attention network (aIPS and FEF) are involved in detecting the presence of arbitrary target objects within natural scenes. We show that the neural decision variables extracted from the classification analysis correlated with observers' decision confidence and with ensemble observer behavior elicited by an image, indicating a robust correlation between behavior and neural activity during search of natural scenes.

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56.417 ERP correlates of the target representation used to guide search

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Effective search guidance requires the creation, maintenance, and matching of a target representation in memory to objects in the environment for the purpose of generating a guidance signal. We investigated the representation used to guide search by simultaneously recording EEG activity and eye movements while observers searched for pictorially-cued or categorically-cued targets. Observers simultaneously previewed a picture and a basic-level object name for 400ms, followed by a ~2.75s delay and finally a search array depicting four real-world objects. Under blocked instructions either the pictorial or categorical cue (not both) was designated as the search target. The task was to fixate the target and simultaneously press a button; targets were always present. Trials were segregated into strong-guidance (target was the first object fixated) and weak-guidance (target was not the first object fixated) groups, and the contralateral delay activity (CDA, an electrophysiological marker for WM load which is modulated by task-relevant features and/or locations), was computed in response to cue onset for each group and cue condition. We evaluated a time window of 300-900ms after cue onset and found that the magnitude and direction of the CDA at lateral-parietal sites interacted with the type of cue. Pictorial cues showed common CDA, consistent with target related visual details being held in WM. However, categorical cues showed inverted CDA (contralateral more positive than ipsilateral), possibly suggesting a target representation less reliant on visual information. Moreover, lateral-parietal sites were not found to distinguish between strong and weak search guidance. Only after exploring CDA at frontal sites in the same time window did we find activity correlated with later guidance to the search target. In accordance with the biased-competition model, we interpret this as evidence for the frontal modulation of the representation used to guide search via the selection or biasing of task-relevant target features.

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56.418 fMRI responses during visual search predict the magnitude of EEG and behavioral benefits of repeated context

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In visual search tasks, there are clear performance benefits when the spatial configuration of targets and distractors is repeated -- a phenomenon known as the contextual cueing effect (Chun & Jiang, 1998). Initial accounts suggested that this benefit emerges out of an interaction between the neural mechanisms involved in attention and those involved in long-term memory (e.g., hippocampus), but evidence for this hypothesis has been mixed (Chun & Phelps, 1999; Manns & Squire, 2001; Greene et al, 2007; Preston & Gabrieli, 2008). Here we investigated the neural bases of the contextual cueing effect by probing the relationship between hippocampus responses recorded using fMRI and both the size of the attention-related N2pc event-related potential and the behavioral contextual cueing effect. Eleven subjects performed a visual search task in two sessions, each consisting of 256 trials (50% repeated configurations). In session 1, 64-channel EEG and whole-brain fMRI data were acquired simultaneously. Session 2 occurred one week later and was identical to session 1, except that only 64-channel EEG data was recorded. A hippocampal region-of-interest (ROI) was defined a priori and the BOLD percent signal change was computed for repeated and novel displays. A rank-ordering analysis was used to assess the relationship between the hippocampus, the N2pc, and behavior. This analysis revealed that the magnitude of the difference between repeated and novel displays in the hippocampus ROI could rank order individuals based on the size of the cueing effects observed in session 1 (60%) and session 2 (56%) significantly better than chance ($p < 0.01$). Hippocampal activity also accurately rank ordered the size of the N2pc from session 1 (56%) and from session 2 (64%, both above chance, $p < 0.01$). These results illustrate that the response of the hippocampus early in learning can predict the level of eventual behavioral benefit of repeated spatial configurations.

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3D perception: Natural and virtual scenes

Tuesday, May 10, 3:00 - 7:00 pm

Orchid Ballroom, Poster Boards 419 - 434

56.419 Depth Compression and Expansion in Photographs

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Photographs taken with long focal length lenses appear to be compressed in depth and those taken with short focal lengths appear expanded. A common rule in photography is to use a 50-mm lens to create a natural-looking image (i.e., neither compressed nor expanded in depth). We hypothesized that this rule is a byproduct of people's viewing habits and an inability to take viewing distance into account. The retinal images generated by a photograph and the original scene are the same when the viewer is at the photograph's center of projection (CoP). The distance of the CoP is the lens focal length multiplied by the print magnification. When viewers look at a photograph from closer or farther than the CoP, the geometric information in the retinal image specifies a scene that is respectively expanded or compressed. To test our hypothesis, we conducted an experiment examining how CoP distance, print size, and image content affect preferred viewing distance. Observers adjusted their distance from photographs with different CoP distances and print sizes until the distance was "best to view from." In agreement with studies of television viewing, preferred distance was mostly determined by print size. There was a small effect of CoP distance, due mostly to viewing portraits. Generally, observers stood too far from photographs with short CoP distances (short focal lengths) and too close to ones with long CoP distances (long focal lengths). Coupled with an inability to take distance into account when interpreting 3D contents of the photograph, this causes perceived expansion and compression with short and long focal lengths, respectively. The effects are minimized when the focal length is 50-70mm, which is consistent with common practice in photography. Our results offer guidelines for creating images—photographs, computer-generated, perspective paintings—with the desired perceived depth.

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56.420 Measuring pictorial space in paintings: Converging operations

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Although a picture is a flat object covered with pigments, human observers often experience a 3D "pictorial space" when looking "into" the picture. This space is a mental entity, apparently triggered by so-called pictorial cues. In the case of paintings or drawings, the visual artist has put patterns of pigment on the canvas to trigger certain experiences in prospective viewers. Several experiments were carried out with the same stimulus, a copy of a wash drawing by Francesco Guardi, representing an imaginary landscape with much pictorial depth but no "ground truth". In a first series of experiments, we selected 5 points that were well-localized in pictorial space. On each trial, one of these points was designated as target and another one contained a 3D pointer, whose slant and tilt values could be adjusted by the observer until it appeared to point to the target, in the perceived 3D space. In a second series of experiments, 49 localizable points were selected and on each trial two points were marked. Here, observers simply had to indicate which of these points appeared closer in depth relative to the viewer. In a third series of experiments, 10 of these points were selected and presented in pairs. Now, observers could adjust the relative sizes of two discs on these locations, making use of size constancy to indicate the perceived relative distances between them. We have explored various methods to operationalize the geometrical properties of the 3D space as perceived by the viewer. Examples include pictorial depth, either in a metrical or a mere ordinal sense. In general, we find that different observers tend to agree remark-

ably well on ordinal relations, but show substantial differences in metrical relations (scaling). Moreover, when comparing the results of the different methods tested on the same observers, we find considerable consistencies.

Acknowledgement: METH/08/02

56.421 Depth-of-field in (semi-)natural photographs

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Depth of Field is roughly defined as the depth range that is perceived to be sharp in the photograph. Although earlier research has shown effects of depth of field in simple scenes, it is unclear what the effect of depth of field is in semi-natural scenes in which there is a redundancy of depth cues. I made four different semi-natural scenes consisting of a central and two flanking figurines. For each scene, I made a series of photos in which the depth between the central the flanking figurines was increasing in small steps. I made these photo series with six different Depths of Field. In the first experiment participants had to adjust the position in depth of the two flanking figurines relative to a central figurine, by toggling through the photos, such that the perceived depth equaled the perceived lateral distance between the two flanking figurines. Viewing was either monocular or bi-ocular (non-stereo). In the second experiment, I varied the viewing distance. I found that participants' depth / width settings increased with increasing Depth of Field. In other words, when the Depth of Field increased, the perceived depth decreased. Participants made lower settings for monocularly seen stimuli than for bi-ocularly seen stimuli and decreased when the viewing distance was increased. The effect sizes of viewing mode and viewing distance were in the same order as the effect size of the Depth of Field over the experimental range. I conclude that in photographs of (semi-) natural scenes, in which depth cues within the image are highly redundant, and where there are plenty of conflicting depth cues as well, depth of field is an important cue that is taken into account in the perception of depth.

56.422 A dense sampling method for calibrating non-see-through head mounted displays

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Immersive virtual reality is becoming an increasingly powerful tool for studying visuo-spatial perception in moving observers. However, the validity of results depends critically on an accurate calibration of the visual display. We have developed a system for calibrating a head mounted display (HMD) using camera calibration techniques (Gilson et al., *J. Neuroscience Methods*, 173, 2008). Here, we describe a new method that allows a very large number of sample points to be gathered, leading to significant improvements in the accuracy of the recovered HMD frustum parameters. This improved accuracy allows us to test one of the key assumptions underlying the method. A camera was placed inside a stationary HMD where it recorded a chequerboard image shown in the HMD display. The position and orientation of the HMD was also recorded by a 6 degrees-of-freedom tracking system. Without moving the camera, the HMD was removed and images taken of a tracked calibration object that moved along a pseudo-random trajectory within the field of view of the camera. The technique allows camera coordinates of the calibration object to be translated to HMD coordinates. We used standard camera calibration techniques to recover the optical parameters of the HMD (not the camera) and hence derive appropriate software frustums for rendering virtual scenes in the binocular HMD. The recovered frustum has an optic centre coincident with the camera optic centre. We demonstrate the implications of this by introducing small shifts of the camera relative to the HMD. Our calibration method represents a significant advance over previous methods as it requires no detailed judgements by an expert user wearing the HMD (c.f. SPAAM, Tuceryan et al., *Presence-Teleop. Virt.*, 11, 2002); it works for non-see-through HMDs; and it provides a quantitative measure of calibration accuracy, with reprojection errors of as little as 1 pixel (RMS).

Acknowledgement: Wellcome Trust

56.423 **The influence of a scaled third-person animated avatar on perception and action in virtual environments**

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Newer technology is allowing for virtual environments to become more realistic by providing visual image quality that is very similar to that in the real world. Regardless, egocentric distances estimates in virtual reality have been shown to be underestimated (Thompson et al., 2004). Interestingly, this underestimation decreases after individuals view self-representing avatars in the virtual environment; especially when the avatars are self-animated (Mohler et al., 2010). These findings support perspectives on embodied perception which assert that the body and its action capabilities can act as a "perceptual ruler" that the perceiver uses to scale the world. To test this perspective, we immersed participants into a full-cue, virtual environment where they viewed a self-animated avatar from behind at a distance of 3.5m away at the same eye-height as the avatar. We manipulated the relationship between the size of the avatar and the size of the virtual room (which included familiar objects) to see if participants would attribute these changes either to the size of the world or to the size of their body. Participants made verbal estimates about the size of self and the world and performed a walking-in-place task. We found that participants verbally attributed the apparent size difference to the virtual world and not to the self which suggests that space perception is grounded in the physical body. Further, we found an influence of condition on the post/pre walking-in-place drift suggesting that the participants felt embodied in the third person animated avatar. Further research needs to be conducted in order to fully understand the relative importance of visual cues about self, such as motion coupling, eye-height and distance of avatar from observer, on perception and action in virtual worlds.

56.424 **Welcome to Wonderland: The Apparent Size of the Body Influences Perceived Extents in Virtual Environments**

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According to the functional approach to the perception of spatial layout, angular optic variables that indicate extents are scaled to the action capabilities of the body (see Proffitt, 2006, POPS, for a review). For example, reachable extents are perceived as a proportion of the maximum extent to which one can reach, and the apparent sizes of graspable objects are perceived as a proportion of the maximum extent that one can grasp (Linkenauger, et al., 2009, JEP:HPP; Linkenauger, Ramenzoni, & Proffitt, 2010, Psychol Sci; Witt, Proffitt, & Epstein, 2005, JEP:HPP). Therefore, apparent distances and sizes can be influenced by changing the action capabilities of the body. In order to directly manipulate the perceived action capabilities of the body, participants were immersed into a full cue virtual environment. In real time, participants' hand, arm, and head movements were mapped onto a self-avatar which the participant viewed from the first-person perspective via a head-mounted display. To manipulate perceived action capabilities, the apparent size of the participants' hand was altered by decreasing or increasing the size of the self-avatar's virtual hand (small, normal, and large). Participants estimated the sizes of various objects in the virtual environment. Participants perceived objects to be larger when their virtual hand was smaller and perceived objects to be smaller when their virtual hand was larger. Consistent with the functional approach, the differences in apparent size across the conditions increased as a function of object size, suggesting changes in the scaling metric rather than a constant bias.

56.425 **Bringing the real world into the fMRI scanner: Robust release from adaptation for 2D pictures but not actual 3D objects**

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Our understanding of the neural underpinnings of perception is largely built upon studies that have employed 2-dimensional (2D) planar images. When viewing a sequence of two 2D pictures of objects, a change in objects produces a characteristic release from adaptation within ventral visual object-selective areas. Here we use functional brain imaging in humans to examine whether neural populations show a similar effect for real-world

3-dimensional (3D) objects. We found robust release from adaptation for 2D images of objects within classic object-selective cortical regions along the ventral and dorsal visual processing streams. Surprisingly however, BOLD responses remained in the adapted state on trials involving different 3D stimuli suggesting broader neural tuning for real-world objects. Our findings indicate that the neural mechanisms involved in processing real-world 3D objects are distinct from those that arise when we encounter a 2D representation of the same items. Incorporating real-world stimuli into fMRI designs may provide a more thorough understanding of the neural mechanisms of human vision.

Acknowledgement: Natural Sciences and Engineering Research Council of Canada, Canadian Institutes of Health Research to the Group on Action and Perception

56.426 **Human recovery of the shape of a 3D scene**

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We have shown that the shape of a 3D object can be accurately recovered from a single 2D orthographic or perspective image. The key to a successful recovery is the operation of a priori constraints: 3D symmetry, 3D compactness, and planarity of contours. Once the entire 3D shapes in the scene are recovered, it is possible to recover the spaces between them and form a complete spatial map. In three experiments, we tested how well a human observer recovers relative positions of objects (the shape of a 3D scene). In Experiment 1, the subject viewed a room, containing several pieces of furniture placed on textureless floor, from a single viewing position, and drew a top view of the room on a tablet computer screen. Two transformations (best rotation and size scaling in the least-squares sense) were applied in order to compare the relative positions of recovered objects to those of real objects. The error was less than 10% of the distance between the subject and the objects. Since the drawing is likely to be affected by the ability to scale sizes and distances, the subjects were asked in the next experiment to remember the positions of the objects and then walk around their positions after the objects had been removed. Performance in this task was as good as that in the drawing task. The contribution of short term memory was tested in the third experiment. The subject viewed a computer screen containing several dots. After the dots disappeared, the subject waited for a period of time (0 to 40 sec) and then reconstructed the map on another screen. The results show that delays of up to 15 sec do not harm the performance. Results of these three experiments show that human perception of 3D indoor scenes is very accurate.

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56.427 **3D symmetry correspondence from 2D images of objects**

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Last year we presented a model that recovered a 3D scene containing symmetric 3D shapes from a perspective image (Catrambone et al., 2010). The 3D recovery was applied to an "organized" image. In particular, the model was given information about which pairs of 2D curves in the image represent pairs of 3D symmetric curves. This is called "symmetry correspondence problem". This problem is fairly easy to a human observer, but the underlying computational mechanisms remain unknown. Symmetry correspondence problem is ill-posed. Specifically, we have recently proved (Sawada et al., 2010) that any pair of 2D curves has one or more 3D symmetric interpretations. Therefore, pixel-based or edge-based algorithms will usually fail to detect real 3D symmetry. Here, we present a new computational method which uses higher-level features and which is based on a priori constraints. This method was tested with images of indoor scenes containing furniture, like chairs, and tables. The analysis of an image begins with detecting edges of approximately rectangular objects and grouping the edges into one of three groups corresponding to three different vanishing points (see Hedau et al., 2009). One vanishing point corresponds to the mirror symmetry of the object. The next step is to detect 'C' or 'S' curves that consist of two "L" junctions. Such curves, being higher order features, are not accidental. Two 'C' or 'S' shapes are considered to be symmetric if the lines connecting the corresponding "L" junctions pass through the vanishing point. After detecting all symmetric 'C' and/or 'S' shapes, the algorithm forms a list of corresponding (symmetric) edges. Several additional processes, like the computation of the distances between the corresponding

edges and removing possible outliers, were applied to remove spurious (false) correspondences. The algorithm was tested on tens of real images and shown to be robust for non-degenerated views.

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56.428 On the role for binocular cues in the fast extraction of egocentric distance

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Previous research has shown that humans can estimate the distance to viewed targets (floor-level, 3-5 m distant) with near perfect sensitivity (slopes near 1), even when targets are viewed in single brief glimpses of 100 ms or less. However, performance at brief viewing durations is marked by a bias toward underestimation that is relieved with longer viewing durations. Does the high sensitivity to distance at brief viewing durations depend on binocular viewing, and should the underestimation at shorter viewing durations be attributed to a relatively long time course for the availability of binocular cues? To address these questions, participants verbally estimated target distance under monocular and binocular viewing conditions with viewing durations of 74 and 1200 ms. Viewing durations were administered in blocks with block order manipulated between groups. Bias and sensitivity each depended on block order, suggesting that verbal reports may be particularly susceptible to carryover effects. Analyses thus focused on first block performance. Sensitivity to distance was generally high but depended on viewing duration: participants were over-sensitive with 1200-ms trials (slope = 1.39) but not with 74-ms trials (slope = .72). Importantly, in both cases sensitivity was undiminished by monocular viewing. Underestimation bias was high with 74-ms trials (-45%) but nearly eliminated with 1200-ms trials (-9%). Experiment 2 controlled for carryover effects by administering monocular trials first in single block followed by a block of binocular trials (74 ms only). Performance was similar to that of Experiment 1 and, critically, sensitivity did not differ between viewing conditions. In sum, the results of these experiments indicate that neither sensitivity nor bias correction depends on binocular viewing. Overall, the data suggest that binocular cues do not play a role in performance within the manipulated distance range.

56.429 The role of depth and frontal planes in perceiving distances in a virtual environment.

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In real and virtual spaces, distances are egocentric (from viewer to a target) or exocentric (between two targets). In real spaces, egocentric distances are estimated accurately and exocentric distances are overestimated when compared to geometric accuracy. In head-mounted displayed virtual environments (HMD-VEs), egocentric distance judgments to targets on the ground are underestimated compared to estimates made in real spaces. However, the accuracy of exocentric distance perception in HMD-VEs, compared to estimates in real spaces, is unknown. Here, we investigated judgments of egocentric and exocentric distance perception in HMD-VEs in comparison to estimates made in an analogous real space. In all experiments, participants viewed a distance then turned and walked a distance without vision. They matched the interval by walking the extent between themselves and the targets (egocentric) or the extent between two targets (exocentric). In both environments, participants were allowed to move their heads to view the targets but were not permitted to move their bodies from the home location. In Experiment 1, participants estimated the egocentric extents in depth and exocentric extents in the frontal plane. Like previous research, estimates of egocentric distances in the HMD-VE were underestimated compared to real world estimates. However, estimates of exocentric distances did not differ between spaces. In Experiment 2, we manipulated orientation of displayed exocentric distances. Participants estimated exocentric distances oriented in depth and frontal planes. Again, results showed that exocentric distances oriented in the frontal plane were estimated similarly in both spaces. However, exocentric distances oriented in the depth plane were underestimated in the HMD-VE compared to the real space. The results suggest that underestimation of distance in HMD-VEs

does not generalize across depth and frontal planes. Work is underway to confirm results with another measure that does not recruit walking strategies, to control motion parallax, and to test possible mechanisms.

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56.430 Two distinct angular perceptual variables account for the dissociation between egocentric and exocentric distance perception

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We propose that the well-known dissociation between egocentric and exocentric distance perception (e.g., Loomis et al., 1992) is based on a distinction between two angular perceptual variables. Errors in exocentric distance tasks, such as the one underlying Gilinsky's (1951) experiments and the perception of depth/width ratio can be explained by biases in perceived optical slant. Errors in egocentric distance tasks, such as egocentric distance estimation, can be understood in terms of biases in the perception of angular declination. Whereas exocentric distance estimates typically demonstrate increasing compression with distance, egocentric distance estimates are normally compressed by a fairly constant amount. Li and Durgin (2010) have shown that exocentric aspect ratio tasks can be used as implicit measures of perceived optical slant which increase logarithmically with viewing distance. Here we further propose that explicit egocentric distance estimation can be treated as an implicit measure of perceived angular declination, which is biased in a linear fashion. To clarify that type of visual information matters more than type of task, we used an egocentric version of the depth/width aspect ratio task. Participants stood at one leg of an L-shape formed by them with two experimenters and were asked to position themselves the same distance from the central experimenter as the central experimenter was from the experimenter at the other leg of the L. Participants set themselves much too far from the central experimenter for all tested distances, consistent with overestimation of angular declination by a factor of about 1.5 (i.e., underestimation of egocentric distance by about 0.7). The egocentric aspect-ratio task provides evidence convergent with other explicit forms of egocentric distance estimation that perceived egocentric distance is underestimated. It also provides implicit quantitative confirmation of explicit evidence for the expanded coding of perceived angular declination, a variable important for motor control and spatial updating.

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56.431 Manipulating Embodiment in Imagined Spatial Perspective Taking

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Spatial perspective taking is the ability to imagine a perspective from a location in space that is different from one's current physical location, requiring a transformation of one's egocentric reference frame. While observers are able to accomplish this task quite well, it is unknown how closely an imagined perspective is tied to the physical representation of the body. We manipulated two factors that could contribute to embodiment in spatial perspective taking: real-world experience in perspective taking and the presence of a visual avatar in the display. Participants completed a real-world version of a spatial perspective taking task prior to a computer-based version, by either walking to the new location around a table or imagining themselves at the new location, while viewing six colored objects on the table. Following this practice, participants completed a similar computer-based task in which some trials presented a virtual avatar in the imagined location, while others did not. Participants determined the location of one of six colored spheres on the table based on their imagined perspective and responded by indicating left, right, top, or bottom with a button press. The results demonstrate that prior experience with real versus imagined self-movement did not influence time or accuracy to imagine a new spatial perspective. However, the presence of an avatar in the computer-based task reduced response times and increased accuracy rates overall compared to trials with no avatar present. Furthermore, a significant degree of rotation x condition (avatar/no avatar) interaction for response time suggests that the presence of the avatar may change the imagined perspective taking

process. Ongoing studies are examining whether facilitation in perspective taking is similar with a non-body object as well as the neural substrates associated with embodied manipulations.

56.432 **View-based vs Cartesian: explanations for human navigation errors**

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View-based and Cartesian representations provide rival accounts of visual navigation in humans. Here, we compare the ability of models based on each representation to describe human performance for a homing task on the scale of a room (i.e. 3-4m square) in an immersive virtual reality environment. In interval one, participants were shown three very long coloured vertical poles from one viewing location with some head movement permitted. The poles were easily distinguishable, and designed to have constant angular width irrespective of viewing distance. Participants were then transported (virtually) to another location in the scene and, in interval two, they tried to navigate to the initial viewing point relative to the poles. The distributions of end-point errors on the ground plane differed significantly in shape and extent depending on pole configuration and goal location. We compared the ability of two types of model to predict these variations in the distribution of errors: (i) view-based models, based on simple features such as angles between poles from the cyclopean point, ratios of these angles, or various disparity measures and (ii) Cartesian models based on a probabilistic 3D reconstruction of the scene geometry in an egocentric coordinate frame for each interval, coupled with a comparison of these reconstructions for the "goal" and "end" points. We estimated parameters for each type of model using cross-validation, and compared the models based on the likelihood of the validation dataset. For our data, we find that view-based models capture important characteristics of the end-point distributions very well. By contrast, the most plausible 3D-based models have a lower likelihood than many possible view-based alternatives. Our evidence provides no support for the hypothesis that human navigation on this scale is based on a Cartesian model.

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56.433 **The influence of object-ground contact on perception of distance and size under severely degraded vision**

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Important to successful navigation is accurate understanding of one's location relative to other objects within an environment. Past research has reliably revealed that observers are accurate in judging absolute distance in their environments, indicated through walking without vision to a previously viewed on-ground target, both under normal and degraded viewing conditions. However, less research has focused on perception of targets positioned off of the ground plane. This may be especially relevant for navigation under low vision, given the consequences of misperceiving target locations. We explored whether support for Gibson's ground theory (1950) would be found with degraded viewing as has been demonstrated with relative distance under normal viewing conditions (Meng & Sedgwick, 2001). In the current study, normally-sighted observers viewed white spherical targets placed on stands through goggles that severely reduced visual acuity and contrast sensitivity in one of two conditions. In the high-visibility condition, targets were placed on a stand painted black, resulting in high contrast with the gray carpet. In the low-visibility condition, stands were painted gray, making them undetectable under low vision conditions. In two counterbalanced blocks, participants made size and absolute distance judgments to three different sized spheres (.203, .304, or .406 meter diameters) at three target distances (1.5, 2.7, and 4 meters). Participants in the high-visibility condition exhibited accurate distance judgments, whereas low-visibility condition participants drastically overestimated target distances. Similarly, the size of targets in the low-visibility condition was judged to be significantly larger than the size of targets in the high-visibility condition. To allow safe travel for those with low vision, these find-

ings point to the importance of highlighting how potential hazards make contact with the ground plane so that hazards are not perceived as more distant than they are actually located.

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56.434 **An older view on distance perception: Age affects perception of walkable extents**

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Spatial perception is affected by the specific energetic cost required to perform an action. Hills appear steeper to people who are wearing a heavy backpack, are fatigued, or are elderly (Bhalla & Proffitt, 1999). In the current experiment, we examined the effect of age on distance perception. We found that distances appeared farther to older adults as compared to younger adults. Older adults did not overestimate in general, suggesting that the effect of age on distance perception is only for action relevant lengths. Additionally, we showed that certain types of floor surfaces that decrease walking ability, such as plastic, make distances look even farther away for older adults while this effect does not occur in younger adults. These results suggest that a long term decline in physiological potential in older adults affects distance perception and that certain floor types that are harder to walk on amplify this effect.

Scene perception: Features and categories

Tuesday, May 10, 3:00 - 7:00 pm

Orchid Ballroom, Poster Boards 435 - 452

56.435 **Neural coding of location and facing direction on a familiar college campus**

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Determining one's current location and facing direction is essential for successful navigation. How are these two types of information represented in the brain? Electrophysiological recordings in rodents have identified place cells and head direction cells whose firing properties code for location and facing direction respectively. However, complementary research in humans has been lacking. We addressed this issue by scanning University of Pennsylvania students with fMRI while they viewed photographs taken by cameras facing 4 different compass directions (North, South, East, West) at 8 intersections from the Penn campus. Images (17 of each direction at each intersection; 544 total) were presented every 4 s without repetition in a continuous-carryover design (Aguirre, 2007). fMRI adaptation (fMRIa) and multi-voxel pattern analysis (MVPA) were used to identify regions that code: (1) the intersection at which the image was taken, (2) the compass direction faced by the camera, (3) the specific view depicted in the image. Preliminary MVPA results from 4 subjects suggest that both locations and facing directions can be discriminated in the hippocampus, and that these two kinds of information are localized to different hippocampal regions. Scene-selective regions including parahippocampal place area and retrosplenial complex may also contain information about locations and facing directions. Our findings are consistent with the rodent neurophysiology literature and suggest that navigationally relevant information in humans is present in distributed patterns of activity across both neocortical and hippocampal regions.

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56.436 **Diagnostic Objects Facilitate Scene Categorization**

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Human observers can identify the basic-level category of complex visual scenes with great speed and accuracy (Potter, 1975). Although one route to scene categorization might involve analysis of global scene properties such as spatial layout or image statistics (Davenport & Potter, 2004; Oliva & Torralba, 2001), a second route might involve analysis of within-scene objects (Quattoni & Torralba, 2009). To test the plausibility of an object-based recognition mechanism, 16 participants performed a four-alternative forced-choice task in which they identified color photographs of bathrooms, intersections, kitchens, and playgrounds, each of which contained two strongly

diagnostic signature objects (e.g., stove and refrigerator for kitchen, traffic light and car for intersection). Each stimulus was presented for 50 ms followed by a pattern mask. Critically, the photographs could either be presented in their original form or with one or two signature objects obscured by a phase-scrambled mask (leaving the majority of the image intact). Relative to performance on unaltered photographs, obscuring a single signature object increased participants' reaction times by 37 ms and reduced accuracy on the scene classification task by 6%, while obscuring both signature objects increased reaction times by 124 ms and reduced accuracy by 19%. This effect is not simply a consequence of image degradation: even after controlling for the proportion of the scene that was masked, accuracy was significantly worse for scenes with both signature objects occluded than with just one. Although indoor and outdoor scenes were classified with comparable accuracy when one of the signature objects was removed, accuracy was significantly poorer for indoor scenes than for outdoor scenes when both signature objects were removed. Together, these results suggest that scene identification is facilitated by recognition of the objects within them. This process may be more important for the identification of indoor scenes, which often possess similar spatial layouts.

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56.437 Normal scenes seem to last longer than jumbled scenes

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Many findings in perception science suggest that space and time perception are interdependent. However, past research typically used simple stimuli. The current experiments tested whether spatial structure of naturalistic scenes affects perceived duration. In three experiments, scene structure was manipulated by jumbling pictures, which effectively reduces spatial extents (c.f. Varakin & Levin, 2008, QJEP). If spatial processing contributes to duration judgments, the perceived duration of normal scenes should be longer than jumbled scenes (greater extents = greater duration). In all experiments, participants first learned to respond to short (400ms in Experiments 1 and 2; 1000ms in Experiment 3) and long (1600ms in Experiments 1 and 2; 2200ms in Experiment 3) "standard durations". Subsequently, normal and jumbled scenes were presented for one of 7 durations, ranging from the short to the long standard in 200ms increments. Participants indicated whether the duration was closer to the short or long standard. In Experiment 1 (n = 15), there was a main effect of scene jumbling: normal scenes elicited more "long" responses than jumbled scenes (54% vs. 51%). In Experiment 2 (n = 23), "windowpanes" were added to normal and jumbled scenes to equate the number of line terminators. Again, normal scenes elicited more "long" responses (52% vs. 51%). The effect was not significant (p = .19), but there was a significant interaction between actual duration and jumbling (p = .046), apparently driven by simple effects consistent with the hypothesis outlined above. Experiment 3 (n = 19) was identical to Experiment 2, except all actual durations were increased by 600ms. As in Experiments 1 and 2, normal scenes elicited more long responses than jumbled scenes (57% vs. 55%). This effect was marginally significant (p = .06). To increase statistical power, Experiments 2 and 3 were analyzed together. There was a significant effect of jumbling (p = .024). Overall, these results suggest that space and time perception are interdependent (to some degree) in the context of naturalistic scene perception.

56.438 On the speed of material recognition in natural scenes

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Rapid perception of natural scenes has been studied under a wide range of conditions. Yet, little work has dealt specifically with material recognition, so far. Sharan, Rosenholtz & Adelson (VSS, 2009) suggested that the recognition of material categories in real world pictures was remarkably fast and accurate. In contrast, Wolfe & Myers (JOV, 2010) found that visual search for materials was rather inefficient. Therefore, we set out to measure the time course of material categorization in natural images in more detail. We also compared the time course of material categorization with that of object classification. Subjects classified images based on their material or object category. 4 different materials (fabric, wood, stone and metal) were used from the Flickr.com natural image database (Sharan et al., 2009): 50 pictures showing objects made from the material (object condition) and 50 pictures showing close-ups of the material (close-up condition). For the object categorization task 100 pictures were chosen from the COREL database according to the 4 categories: people, means of transport, animals and buildings.

Presentation time was varied from 12ms to 118ms. A pattern mask was presented immediately after the image. Subjects were asked to assign each presented picture to one of the given categories in a 4-alternative forced-choice. In line with earlier results, we found that object categorization was extremely fast. At presentation times of 35 ms, observers reached a performance level of 88% correct. The classification of materials was much slower: at 35ms exposure observers performed at 62% correct and they just barely reached 90% correct at 118ms. Similar to Sharan et al. (2009), we found that material recognition was slightly enhanced in the close-up condition compared to the object condition. Overall, object categorization performance was much faster than material categorization performance, indicating that the later might not be that effortless after all.

56.439 Ordinate and Subordinate Level Categorizations of Real-World Scenes: An Eye Movement Study

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Previous research has tended to study the diagnostic information that facilitates scene categorization at a particular level of detail (e.g., the ordinate level: a room, a field, etc.). However, comparatively less research has directly compared the diagnostic information required for categorizing the same scene at multiple levels of specificity. For example, would the diagnostic features that help categorize a scene at the ordinate level as a room also help to categorize the same scene at the subordinate level as a bedroom, or would different information be required? Here, we examined whether the diagnostic information required to categorize scenes at different levels of specificity are located in similar or different spatial regions. In order to address this question, we presented participants with four ordinate-level categories of gray-scale scenes, with each category having exemplars from a further four subcategories. Participants categorized each scene either at an ordinate (e.g., room) or subordinate (e.g., bedroom) level in a four alternative-forced-choice task. Participants viewed scenes through a gaze-contingent window that presented full-resolution information to the fovea and low-passed information to the extrafoveal visual region. Participants therefore always had access to a scene's coarse, spatial-layout, while finer, local details were only available through fixation. By analyzing the resulting fixations as a function of task, we investigated whether the diagnostic information for categorizing scenes at the ordinate and subordinate levels were the same or different. Fixations directed toward similar regions across categorization tasks would indicate that similar diagnostic information is required, while fixations directed toward different regions would suggest that different sets of information are diagnostic. Analyzed behavioral and fixation data showed that in most of the subcategories, the distribution of fixations differed significantly. The results therefore suggest that the diagnostic information required for making categorizing judgements often occur in separate spatial regions of the scene.

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56.440 A new perceptual paradigm and psychophysical evidence for hierarchical gist recognition

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The "gist" of a visual scene is often synonymous with its basic-level category (e.g. coast, street) and the remarkable ability of humans to recognize it both rapidly and accurately is highly useful in everyday life. Following the seminal studies by Rosch et al. (1976) and Tversky & Hemmenway (1983), it has been assumed that basic-level categorization is privileged over the superordinate-level (i.e., indoor vs. outdoor) because it maximizes both within-category similarity and between-category variance. However, recent research has begun to challenge this view (e.g., Fei-Fei et al., 2007; Loschky & Larson, 2008, 2010). Here we make study these directions more fundamentally by investigating the perceptual relations between scene categories to determine whether or not gist recognition is a hierarchical process, and if so, what hierarchical structure does it exhibit in humans.

We introduce a novel psychophysical experimental paradigm - the category discrimination paradigm - where we briefly present two real-world scene stimuli simultaneously for different presentation times and ask subjects to respond whether they belong to the same basic-level category or not. As we show, proper analysis of the obtained data can reveal hierarchical percep-

tual distance between different scene categories and a corresponding hierarchical structure at the perceptual processing level. In particular, we show that the decision whether the scene is man-made or natural is made first, and only then followed by more complicated decisions (such as whether a man-made scene is indoor or outdoor), when fewer candidate categories are still viable. We argue that this observed hierarchical structure not only improves performance, but is also faster to execute in both biological or artificial visual systems.

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56.441 Responding to the gist of unseen scenes

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People can extract the gist of complex scenes (e.g. natural or urban) so rapidly that it has been proposed that scene categories are extracted in the initial, feed-forward sweep of information processing. If so, initial gist processing might resist object substitution masking (OSM), which is thought to interfere with the reentrant, feedback processing considered to be needed for conscious experience of stimuli. If a scene is blocked from awareness by OSM, is its categorical status still computed? Seventeen observers saw displays of three textures and one target that could be either a scene or a texture. The target was surrounded by four small, identical scenes (the mask). OSM was produced when mask offset was delayed relative to target offset. Observers' primary task was speeded discrimination of the category of the mask stimuli (urban/natural). The secondary task was identifying the target as scene or texture. Secondary task performance was 67% correct if mask offset was simultaneous with target offset (no OSM) but only 54% in the delayed offset, OSM conditions. The secondary task significantly influenced the primary. When the target was reported, RTs for mask identity were faster when target and mask were compatible (1095 ms) than when they were incompatible (1158 ms). In the OSM condition, with the target not seen, an effect remained but it was reversed. Compatible was slower (1164 ms) than incompatible (1110 ms). Either way, this shows an influence of the secondary task target on the primary response to the mask's identity. The effect is of most interest in the OSM condition when the identity of the target does not reach awareness. The gist of unseen scenes effects the categorization of other scenes. This gives credence to the hypothesis that feed-forward, non-selective processes are adequate to determine at least some aspects of scene gist.

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56.442 Natural scenes are robust to bubbling

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Human observers are remarkably adept at extracting information from natural scenes. People can detect objects in scenes at very fast time courses (Thorpe et al., 1996), with limited visual attention (Li et al., 2002), and in the presence of occlusion (Meng & Potter, 2008). Here, we further investigated viewers' ability to identify the category of a scene under conditions of occlusion by "bubbling" target images; targets were sometimes displayed through five or more randomly positioned apertures, with radii chosen so that 20% - 80% of the images' original area was visible. Images had previously been rated as "good" (highly representative) or "bad" (least representative) exemplars of six natural categories: beaches, city streets, forests, highways, mountains, and offices. Participants were shown rapid sequences of three photographs and asked to indicate whether the category of the second (target) image was the same or different from that of the first and third images (which always belonged to the same category). We observed significant effects of both representativeness and occlusion on categorization performance, with higher accuracies for good category exemplars and lower levels of occlusion. However, even with only 20% of the original image visible through the bubbles, participants' performance

remained above chance for both the good and bad exemplars. These results support previous reports on the robustness of scene perception to occlusion, but show that this manipulation does impair category recognition.

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56.443 Varying image perspective weakens the leaning tower illusion.

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The leaning tower illusion occurs when two identical images of the Leaning Tower of Pisa are placed side-by-side to each other. When this occurs, the two towers appear to be leaning at two different angles. Discovered by Kingdom, Yoonessi & Gheorghui (2007), they proposed the illusion works because our visual system tends to group two side-by-side objects as being the same scene. As both tower images have identical parallel outlines, yet cannot be parallel in the physical world, our knowledge of perspective compensates, causing the perception of the two towers diverging. Here I wanted to explore if our knowledge of perspective is the cause of the illusion. Before testing the hypothesis, a measure of illusion strength needed to be defined. This led to the thought: could increasing the distance between the two images cause the illusion to weaken? 20 observers performed a method of adjustment task, where they increased or decreased the distance between the two images. Each participant performed 100 trials (50 up/50 down) per condition. On average, participant still reported the illusion with a gap of 8.7° (sd=.57) between the two images. Next, a CGI version of the tower was created, allowing for manipulations of perspective and image structure. The CGI image results in a similar gap size for the illusion. However, when the sense of perspective is enhanced by reducing the convergence point, then illusion strength is reduced, requiring a smaller distance (6.8°, sd=.38, d=3.9) between the two images to maintain the illusion. A similar result is also obtained when the perspective is reduced by increasing the convergence point (7.2°, sd=.48, d=2.8). Other image manipulations (low & high-pass filtering, inverting image, distorted horizontal and vertical contours) had no effect on the illusion strength. These data suggest that the leaning tower illusion requires our knowledge of perspective to cause the illusion.

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56.444 Perceiving multiple scene events at the grand time scale of seconds

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Scene perception research has focused on brief events at the time scale of milliseconds. Humans, however, are more practiced perceiving events lasting seconds. How important is attentional set at this more natural time scale?

Extending previous work, we used relatively simple displays with 4 simultaneously active objects and 2 event types. The events were human figures animated over 2.4 sec lifetimes. In the motion task, walking figures swung their arms; targets also clapped once. In the color task, the figures were static and shirt color changed slightly, or more for targets. During each 24 sec trial, there were 36 animated tokens and 4 of them became targets (requiring responses). Perceptual efficiency was measured in terms of sensitivity.

To learn about attentional set, we varied the events -- the figures varied in orientation or task. In Experiment 1, tokens varied in orientation (2 orientations differing by 90 deg rotation). Relative to single-orientation conditions, perceptual efficiency was reduced by varying orientation, indicating that object orientation is part of the attentional set. In Experiment 2, a single orientation was used but the tokens varied in task (color or motion). Relative to single-task conditions, perceptual efficiency was reduced by task variation, confirming that task is part of the attentional set. In Experiment 3, we compared single-orientation, single-task conditions to mixtures of orientation and task. The reduction in perceptual efficiency due to orientation+task variation was greater than the sum of costs of varying orientation or task only. This suggests that task and spatial orientation are both integral to attentional set. The results provide further evidence that attentional set, including spatial properties of set, is important for scene perception at natural time scales, even when the number of objects was within object-attention limits.

56.445 Does language influence how visual events are perceived?

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We investigated how visual processing and linguistic processing interact by determining the extent to which people's interpretations of visual scenes is affected by the sentences used to describe these scenes. Thirty-one college students watched captioned videos in which 10 shapes were moving. In a third of the trials, all 10 shapes moved randomly ("random" trials). In the rest of the trials, one shape "chased" another shape (against a background of 8 randomly moving shapes), with the distance between the two shapes being either 60 pixels or 120 pixels.

A caption appeared under each video (even the "random" videos) that read "A SHAPE is VERB-ing a SHAPE2", where VERB referred to 1 of 4 verbs (chase, flee, lead and follow). Notice that all 4 verbs can be used to describe the same visual scene, albeit from different perspectives. After each video, subjects answered the question "Was a SHAPE1 VERB-ing a SHAPE2?"

Analyses revealed that how quickly a "chasing" event was detected WAS affected by visual characteristics of the videos (e.g., whether there was chasing and, if so, the distance between the shapes), but was NOT affected by the linguistic content of the captions (the sentence's verb and veracity). This finding is consistent with linguistic information not affecting the visual percept of an event. Conversely, how quickly a query was answered WAS affected by the linguistic content of captions (the sentence's verb and veracity), but was NOT affected by distance between the objects (a strictly visual characteristic that was not encoded in the caption). This suggests that perceptual information has relatively little residual impact on a linguistic task, once the visual percept is encoded. Taken as a whole, these results suggest that, at least during the early phases of processing, visual processing and linguistic processing are fairly independent of one another.

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56.446 Sensitivity to the aesthetic value of scenes in the parahippocampal place area

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Previous work has shown that the parahippocampal place area (PPA) responds to physical qualities of a visual scene such as openness and geometric layout (Pegors and Epstein, VSS 2010). "Aesthetic value" is a more abstract visual quality that has also been revealed to correlate with activity in higher-level visual regions (Chatterjee et al. 2009). While one recent experiment has suggested that the PPA responds more strongly to aesthetically-preferred scenes (Yue et al. 2007), it is unclear how this effect interacts with PPA sensitivity to geometric quantities such as layout. We explored this question by scanning subjects with fMRI while they made aesthetic preference ratings of scenes which contained varying degrees of openness. Behavioral data showed that open scenes were judged as more aesthetically pleasing than closed scenes. fMRI data revealed that both openness and scene preference were, in fact, negatively correlated with BOLD activity in the PPA. When openness was controlled, there was no significant effect of scene preference on PPA activity. These results indicate that activity in the PPA is not primarily modulated by the dimension of aesthetic preference per se, but is instead highly sensitive to other scene characteristics that may indirectly affect aesthetic judgments.

56.447 Tuning of human occipitotemporal cortex to sensory, semantic and emotional features during visualisation

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Mental imagery has fascinated philosophers, scientists and the public alike since antiquity. Neuroimaging now offers a window into this most personal of experiences. Multi-voxel pattern analysis (MVPA) of fMRI signal has successfully distinguished between a small number of imagined items/categories, and the neural activity pattern during visualization of an object has been shown to share similarities with that during perception. However, neuroimaging has not yet been used to characterise the content of complex mental images in any detail. Which stimulus features are being represented? Which aspects of the representation are shared between mental imagery and perception? Here we combine pairwise pattern-analysis of a rich stimulus set, with novel, adaptive stimulus selection, to provide precise, simultaneous characterisation of multiple facets of particular mental

images, as represented by human occipitotemporal cortex. Across a large set of 200 naturalistic images, we identified those that when viewed evoked the most similar activation pattern to a predefined referent image. These stimuli we term the "neural neighbourhood," and by examining which features they share, the neural representation of the referent was characterized along various feature dimensions. In two critical manipulations, we varied the identity of the referent image, and whether it was freely viewed or merely imagined. We find coding of precise semantic category and of emotional content, abstracted from low-level sensory properties. The balance of tuning along the various feature dimensions is dependent on the particular referent, and whether it was being viewed or imagined.

56.448 Natural Scene Image Complexity Differentially Modulates the N1 and P1 Components of Early VEPs

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The contrast response function of early visual evoked potentials (VEPs) elicited by sinusoidal gratings is known to contain characteristic potentials closely associated with parvocellular and magnocellular processes. Specifically, the N1 component has been linked with parvocellular processes, while the P1 component has been linked with magnocellular processes. Recently, we examined the extent to which these components are modulated by the physical characteristics of natural scene imagery that varied according to image complexity (i.e., density of edges and lines within the imagery) as well as the distribution of contrast across spatial frequency (SF) (Hansen et al. 2010, VSS). We found that the N1 and P1 components differentially respond to natural scene images; with the P1 component being mostly modulated by the distribution of contrast across SF, and the N1 component being entirely modulated by image complexity. However, since natural scenes are broadband, it was not possible to determine whether this differential modulation resulted from interactions within or between the neural processes associated with the P1 and N1. Here we sought to address this issue by using band-pass filtered natural scene image stimuli varying in image complexity. Stimuli were filtered to preserve a 1-octave band of SFs centered on either 0.8cpd or 8.0cpd. EEGs were recorded while participants viewed each SF filtered natural scene image (500msec). For the 8.0cpd condition, the results show the N1 component to be entirely modulated by image complexity (larger N1 magnitudes for more complex imagery). Critically, for the 0.8cpd image condition, the P1 was also modulated by image complexity, but in the opposite direction. These results suggest that the N1-P1 component modulation previously observed with broadband images consists of an interaction between the neural processes associated with each component, with the neural processes associated with the N1 possibly acting to suppress the image complexity response of the P1 component.

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56.449 Dissociating object and space representations in scene-selective visual cortex

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Neuroimaging studies have identified a network of scene-selective cortical regions: Parahippocampal Place Area (PPA), Retrosplenial Complex (RSC) and Transverse Occipital Sulcus (TOS). However, the different contributions of these areas to scene recognition are unclear. Further, while PPA shows a stronger response to scenes than objects it also contains significant object information. To reconcile these findings and elucidate the nature of scene processing in each region, we assessed the relative impact of objects and spatial backgrounds on responses. We manipulated object and spatial information by generating minimal scenes comprising one of seven objects (or no object), presented on one of three different backgrounds differing in the spatial information they contain (room interior, horizon, and luminance gradient). The horizon and room backgrounds conveyed depth information, but only the room defined an enclosed space. Unlike other studies using real-world, but visually uncontrolled scenes, these minimal scenes provide a simple controlled test of the relative contribution of objects and backgrounds. Individual scenes were presented in an ungrouped event-related fMRI experiment and the distributed response patterns to each were analyzed using split-half correlations. Response patterns in scene-selective cor-

tex discriminated both objects and backgrounds. However, different scene-selective regions emphasized different aspects of the scenes. RSC primarily reflected the spatial aspects of the scenes, discriminating backgrounds regardless of objects and showing no modulation of response strength by object presence. In contrast, PPA and TOS responded more strongly in the presence of an object and showed strong discrimination of objects as well as backgrounds. However, object discrimination in PPA, but not TOS, was modulated by the type of background, with the strongest discrimination against room backgrounds. We conclude that while RSC mainly represents spatial information, PPA and TOS represent both object and spatial information to provide a rich representation of the visual environment.

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56.450 **The occipital lobe in detection and categorization abilities: an fMRI study in healthy individuals**

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Previous studies led to controversial data about an intrinsic relationship between visual detection and categorization abilities. To assess if a difference could exist as early as the occipital lobe, we submitted 14 healthy male volunteers (55 years \pm 11.4) to an fMRI paradigm including a detection and a categorization task differing only by the task demand. In the detection task participants had to press one button when a natural scene image was presented and another one when a null stimulus was presented; ii) in the categorization task they had to press a button when an image of city was presented and another button when an image of a highway was presented. Images were either filtered (high or low spatial frequency [HSF or LSF]) or not. Except for the task demand, the two tasks did not differ one from the other. Behavioural data revealed that, in the detection task, HSF processing was significantly longer and less accurate than LSF and NF processing. There was no significant difference between LSF, HSF and NF in the categorization task. Although the two tasks were "physically" identical and differed only regarding the cognitive demand, neuroimaging data highlighted that the two tasks recruited a differential network even in the occipital lobe. Whereas the detection task led to an increased signal in the inferior occipital gyrus bilaterally, the categorization task led to an increased signal in the inferior and medium occipital gyri in the left hemisphere only. Concerning spatial frequencies, the left middle occipital gyrus was significantly more activated when participants had to categorize scenes filtered in HSF than in LSF. Overall, our results suggest an early hemispheric specialization for detection and categorization abilities even when the stimuli and the paradigm are comparable (i.e., when only the instructions changed).

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56.451 **Detection and categorization abilities following peripheral or cerebral visual impairment**

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Literature data suggest that cortical reorganization can occur following peripheral as well as cerebral visual system damage. Nevertheless, visual processing adaptation to either type of damage remains unclear especially in respect to the central visual field (often partly preserved). To better apprehend visual processing in such damages, 8 optic neuritis patients remitted for one month (4 right and 4 left optic neuritis) and 8 patients with homonymous hemianopia (4 right hemianopes and 4 left hemianopes, following a contralateral occipital damage) completed a detection and a categorization task of natural scenes images. They were compared respectively to 16 young and 16 aged healthy controls. Filtered (in high or low

spatial frequencies) and unfiltered images were briefly presented centrally on a computer screen. Participants were required to respond when a natural scene was presented (detection task) or to indicate if the stimulus was a city or a highway (categorization task). Accuracy (error rate) and response times (RT) were recorded. In remitted optic neuritis patients, altered performance was observed with the (previously) pathologic eye (either right or left) compared to their healthy eye or to the young control group. The deficit seemed specific to low spatial frequencies (accuracy) and stronger in the categorization than in the detection task (RT). In hemianopes, although accuracy was not altered in either task or patients groups, left hemianopes showed longer RT in both tasks (regardless the spatial frequency condition) whereas right hemianopes only tended to show longer RT for high spatial frequency in the categorization task (compared to aged controls). Overall our results suggest that central vision is not preserved following either a peripheral or a cerebral visual impairment and that the nature of this deficit depends on the lesion side only for cortical damage, consistent with the anatomical and functional organization of the visual system.

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56.452 **Evidence of a coarse-to-fine categorization of visual scenes using movies of spatial frequency filtered scene images**

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Complex natural scenes are very quickly categorized, faster than 150 ms, suggesting a simple and efficient processing. Recent models of visual recognition have suggested that perceptual analysis may start with a parallel extraction of different spatial frequencies (SF), but using a preferential coarse-to-fine (CtF) sequence of SF processing. A rapid extraction of low spatial frequencies (LSF) may thus provide an initial and crude parsing of the scene, subsequently refined by slow but more detailed high spatial frequencies (HSF). However, a fine-to-coarse (FtC) being sometimes preferred to a CtF sequence depending on task demands. The present experiment aims to investigate whether a CtF processing allows faster scene categorization rather than a reverse FtC processing. To constrain SF processing according to these sequences, we presented brief movies of successive SF-filtered scenes with opposite SF sequences (either from LSF to HSF, or the reverse), allowing us to experimentally "decompose" the visual inputs in either CtF or FtC sequences. Movies last 150 ms and were composed of six SF-images of the same scene, filtered either at 1, 2, 3, 4, 5, 6 cycles/degree of visual angle for CtF movies or the reverse for FtC movies. Thirty five participants performed a categorization task (indoors vs. outdoors) on these movies. Results showed that they categorized CtF movies significantly faster than FtC movies. Using for the first time dynamic stimuli, these results provide critical support to recent models of vision. The current stimuli seem therefore well appropriate to highlight the neural basis of the CtF categorization.

Development: Disorders

Tuesday, May 10, 3:00 - 7:00 pm

Vista Ballroom, Poster Boards 501 - 511

56.501 **Computerized Progressive Attention Training (CPAT) in adults with ADHD – A randomized controlled trial**

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Deficits in sustained attention and in executive attention have been demonstrated to be important in both children- and adult-ADHD. Originally, the computerized progressive attentional training (CPAT) was designed and proved to be effective for children with ADHD. In the present study we investigated whether the CPAT is an effective intervention for adults with ADHD. The CPAT is composed of four sets of structured tasks that uniquely activate sustained attention, selective attention, orienting of attention and executive attention. Performance was driven by tight schedules of feedback and participants automatically advanced in ordered levels of difficulty contingent upon performance. Twenty one adults with ADHD were assigned to the experimental group and received the CPAT sessions twice

a week over an 8-week period. Eighteen age-matched control adults with ADHD were assigned to the control group and participated in sessions of the same frequency, length and format except that instead of performing the attention training tasks they played four standard computer games (Glufo, Filler, String avoider and Tetris) during the session. There was a significant treatment effect for the sustained attention task, both post-intervention and at follow-up (2-3 months after the end of training). Moreover, at follow-up significant treatment effects were emerged for executive attention and impulsivity. This study showed that sustained-, executive-attention and impulsivity can be improved in adults with ADHD. Most importantly, we found significant correlations between the magnitude of improvement in all four functions of attention and both general features (i.e., consistency of performance across all training sessions) and specific features (i.e., the level of difficulty that participants achieved in the selective attention and executive attention training tasks) of the CPAT. We concluded that the attentional improvements were primarily due to the CPAT.

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56.502 The Relationship of Global Form and Coherent Motion Detection to Reading Fluency

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Several psychophysical observations suggest that an array of different developmental disabilities share deficits in functions thought to be specific to dorsal stream processing – namely coherent motion detection (Braddick, Atkinson & Wattam-Bell, 2003). Mechanisms to detect motion coherence have been reported to be abnormal in dyslexics (Eden, et al, 1996), suggesting that reading is related to dorsal visual function. We evaluated two questions: (1) Is reading fluency a function of the dorsal visual stream? (2) Is dyslexia characterized by attenuation of or deviation from typical global form and motion detection ability? We measured detection thresholds for coherent motion and coherent form (Glass patterns) using a standard staircase procedure. We found that in typically developing children, reading fluency is significantly correlated with thresholds of global coherent form but not coherent motion when corrected for nonverbal IQ and age. This suggests that reading fluency is a ventral, rather than dorsal, visual function in typically developing children. Additionally, both children and adults performed better at detecting coherent motion than coherent form; performance on both tasks improved between childhood and adulthood. However, we found that dyslexic adults showed a different pattern of performance from both typical adults and children: Dyslexic adults detected coherent form better than coherent motion. They were also worse than typical adults at both tasks. This pattern of results is indicative of deviation from typical development in dyslexia in global visuospatial processing, rather than mere attenuation. Our results show that detecting global form is related to reading fluency in typical development, but that detecting global motion is impaired in dyslexia.

56.503 Increased Internal Noise Cannot Account for Motion Coherence Processing Deficits in Migraine

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Individuals with migraine, in-between migraine events, have previously exhibited higher coherence thresholds for global motion tasks than headache-free controls. The underlying mechanism is unclear. Studies have proposed that the visual cortex of migraineurs is hyperexcitable either through reduced inhibitory function or increased neuronal excitation either of which may result in increased internal (neuronal) noise. In this study, we examine whether increased internal noise can explain motion processing differences in migraine. The amount of internal noise was estimated using an N-Pass method which requires several runs, or passes, of identical stimuli to be completed by the participant with responses correlated across runs. Internal noise results in inconsistent responses to identical stimuli across different runs. Thirteen participants who experienced migraine (4 migraine with aura, 9 migraine without aura aged: 19-40) and 15 headache-free controls (aged: 24-34) participated in the current study. Participants completed three psychophysical tasks: 1) detecting coherence in a global-motion stimulus, 2) discriminating the spiral angle in a glass pattern and 3) discriminating the spiral angle in a global-motion stimulus. Inclusion of

spiral tasks allowed a comparison of the precision of spiral angle coding in both form and motion stimuli. The method of constant stimuli was used to obtain threshold estimates. There were two levels of external noise (0 and noise sufficient to double threshold) added to the stimuli in the spiral motion and form tasks. Consistent with previous research, migraineurs had significantly higher motion coherence thresholds than controls ($t(25) = 2.36, p < .05$) but there were no significant threshold differences between the same groups on the spiral global-motion and global-form tasks. Internal noise estimates were also equivalent across groups in all of the tasks, suggesting that differences in internal noise levels is not the mechanism driving higher motion coherence thresholds in migraine.

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56.504 Larger BOLD responses to visual stimulation in area V1 in people with migraine with aura.

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In migraine, abnormal visual cortical excitability between headaches could predispose to cortical spreading depression and visual aura. Prior fMRI studies comparing migraineurs with aura (MWA) to controls have produced contradictory results. Using larger sample sizes and carefully matched groups, we tested if primary visual cortex (V1) has increased BOLD responsiveness to photic stimulation in MWA patients compared to migraineurs without aura (MWOA) and controls.

BOLD EPI (160 TRs, 3mm voxels, TR=3, at 3 Tesla) was collected while subjects viewed a 5 Hz flickering checkerboard alternating with darkness. Subjects performed an attention task at fixation. There were 13 subjects in each group (each group age=34.5±6SD, 11 women/2 men). The average amplitude of BOLD response (discarding phase) was obtained for each subject within a V1 region of interest defined anatomically using cortical surface topology (FreeSurfer; O Hinds, 2008). Two-tailed t-tests compared the responses between the populations.

Within V1, BOLD responses were significantly larger in MWA as compared both to controls ($p < 0.017$) and MWOA ($p < 0.038$). This effect was specific to V1: within the occipital lobe excluding V1, there were no differences between the groups (all p 's > 0.1). This effect was specific to patients with aura, as migraine without aura (MWOA) did not differ from controls in any region.

Consistent with the presumed mechanism of photic sensitivity in migraine, a larger BOLD response to light was seen in patients with aura within area V1. As BOLD fMRI measures a neuro-vascular response, we cannot attribute the difference in this study to a larger neural response or greater vascular reactivity.

56.505 Reduced Looming Sensitivity in Primary School Children with Developmental Co-ordination Disorder

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Almost 1.2 million people die each year in road traffic accidents, with fatalities for children aged 5-9 years four times greater than for adults (Toroyan & Peden, 2007). These statistics highlight the need for a road traffic environment that caters for human error and vulnerability (Toroyan & Peden, 2007). For a pedestrian standing at the kerb, the most salient feature of an approaching vehicle is the relative rate of dilation of the retinal image (τ ; Lee, 1976). In order to reliably estimate velocity and time from τ , it is necessary for the rate of looming to be above the perceptual threshold of the observer. Previous research has suggested that children with Developmental Co-ordination Disorder (DCD) may have deficits in visual processing, including dorsal-stream visual motion (Sigmundsson, Hansen & Talcott, 2003). Looming detection thresholds, in eleven children with DCD aged between 6-11 and eleven typically developing age and gender matched controls, were measured under foveal and extra-foveal viewing conditions, for (a) isotropic expansion and (b) isotropic expansion with additional lateral image translation. Our results show that there are situations in which children with DCD may fail to detect optical expansion when the vehicle is 5 seconds away, once the speed of approach exceeds 13 mph. This suggests a developmental immaturity in looming detection sensitivity that may give rise to potential errors in the road crossing behaviour of these children. This research reinforces recommendations outlined by the World Health

Organization (Toroyan & Peden, 2007) to set and enforce upper limits on vehicle speed to 19 mph (30 km/h) on roads with high proportions of child pedestrian activity.

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56.506 The effects of saccades on magnocellular visual function in high and low autistic tendency

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Autistic perceptual differences can be explained in terms of dysfunction of the magnocellular visual pathway [1]. Superior search ability across multiple saccades in autistic individuals suggests that saccadic suppression may be altered in high autistic tendency. In normal controls, suppression of vision during saccades affects predominantly the magnocellular system [2]. Thus we compared the relative contributions of the magnocellular and parvocellular systems during saccadic and fixation conditions in 10 young adults with high and 10 with low autistic tendency, selected from a normal population using Baron-Cohen's autism spectrum quotient (AQ) test. Contrast thresholds for achromatic gratings of low or high spatial frequency (0.2 cpd, 2.0 cpd) presented either during the saccade or after a 100ms delay were measured. Saccadic suppression was observed in for high but not low spatial frequency gratings in the High AQ group. However, suppression was observed for both spatial frequencies for the low AQ group. Nonlinear Visual Evoked Potentials (VEPs) were recorded using a horizontal rectangular (40°x8°) stimulus pseudo-randomly flashing with temporal contrast of either 24% or 96% during eye fixations or during horizontal 20° saccades at a rate of 2Hz. A reduction in the magnocellular derived positivity of the second order kernel response was observed at ~100 ms under saccadic conditions, suggesting that impairment in magnocellular transient attention may be the underlying basis of saccadic suppression. An interaction between AQ, magnocellular physiology and saccade condition may help explain perceptual differences in autism. 1. Sutherland A, Crewther DP (2010) Magnocellular visual evoked potential delay with high autism spectrum quotient yields a neural mechanism for altered perception. *Brain* 133: 2089-2097. 2. Burr DC, Morrone MC, Ross J (1994) Selective suppression of the magnocellular visual pathway during saccadic eye movements. *Nature* 371: 511-513.

56.507 Basic mechanisms of visual attention are normal in Asperger's syndrome

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Introduction: Persons with Asperger's syndrome may show behavioral symptoms of atypical attention. Prior research on basic mechanisms of visual attention in Asperger's syndrome has been based on reaction-time tasks. Since reaction-time tasks confound speed of attention with speed and control of motoric functions, accuracy-based measures are also needed. Purpose: Adults with Asperger's syndrome were compared with a control group with respect to a wide range of basic functions of visual attention using measures of both reaction-time and accuracy. The investigated aspects of attention included processing speed, short-term memory capacity, spatial distribution of attention, minimum effective exposure duration, suppression of distractors, and effects of temporal/spatial cueing. Methods: 12 participants with Asperger's syndrome (IQ: M = 107; SD = 8. Age: M = 28; SD = 7.4) were compared with an age-matched control group of 47 psychology students. The two groups were tested with two well documented tests of basic mechanisms of visual attention: the ANT (reaction-time task; Fan et al., 2002) and a whole/partial report paradigm (accuracy task) analyzed by the Theory of Visual Attention (Bundesen & Habekost, 2008). Furthermore, all participants with Asperger's syndrome were tested with standard measures of autism symptom severity: the Autism Diagnostic Interview-Revised (ADI-R, Lord et al., 1994) and the Autism Diagnostic Observation Schedule (ADOS, Lord et al., 2000). Results & Conclusion: Participants with Asperger's syndrome were similar to the control group on all measures of visual attention. No strong or significant correlations were found between autism severity and any measures of visual attention. The results suggest that basic mechanisms of visual attention are normal in persons with Asperger's syndrome.

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56.508 Enhanced global integration of closed contours in individuals with high levels of autistic traits

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Individuals with autism are superior on visual search tasks such as the Embedded Figures Test (EFT) which require detecting a closed-contour shape from within a more complex structure. One suggestion is that they have a relatively weaker ability to perceive the global compared to local elements of a visual display, however others have argued for no global or 'integrative' deficit. The terms 'local' and 'global' have been given a broad range of meanings in the literature, but here we examine whether specific known global visual mechanisms are active in integrating deformed closed-contour shapes, like targets in the EFT. We tested two groups of individuals with either high or low levels of autistic characteristics determined by the Autism-spectrum Quotient (AQ). As previously observed, performance by the group with high levels of autistic traits (high AQ group) was enhanced relative to the low AQ group across all search tasks. However, contrary to expectations of weaker global pooling, both groups demonstrated global integration of visual information around a closed contour and, moreover, the high AQ group displayed greater integration of the visual information available. While the integration and search tasks were inherently different, improved global pooling of information was positively correlated with search ability, indicative of an enhanced system of processing underlying both. This study presents a new method to capture superior visual performance by those with high autistic characteristics where global processes are quantitatively identified.

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56.509 Integration of disparity and texture cues to slant in adolescents with an autism spectrum disorder.

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Integrating multiple sensory estimates while weighting each according to its own reliability can minimise the uncertainty of the overall estimate. Whilst human adults are able to combine multiple sources of sensory information optimally, recent studies indicate that in typical development this ability does not develop until late childhood (Nardini, Bedford & Mareschal, PNAS 2010). Unusual sensory responses were described in Kanner's (1943) first reports of autism, and multisensory integration has been investigated in several studies (e.g. DeGelder, Vroomen, & Van der Heide, 1991; Keane, Rosenthal, Chun and Shams, 2010). The current study examined how adolescents with autism integrate two visual cues: texture and disparity cues to surface slant. Participants with and without autism (N=13, N=9), aged 12-16 years, were matched on gender and general cognitive ability (Wechsler Abbreviated Scales of Intelligence). We used a 2AFC procedure to measure participants' 75% discrimination thresholds for which of two planes was the more slanted based on disparity and texture cues, singly (D, disparity, slant signalled by disparities of random dots; T, texture, slant signalled by texture gradients of tiled surfaces viewed monocularly), or in combination (DT, slant signalled by disparities and texture gradients of tiled surfaces). We also measured changes in cue weighting in response to manipulations of the reliability of the texture cue. ANOVA showed an effect of condition corresponding to better discrimination given multiple than single cues, and an effect of group reflecting worse overall discrimination in the group with ASD. However, in both groups DT performance was consistent with optimal integration of D and T as predicted by a Bayesian ideal observer model. The ASD group also weighted texture less when it was less reliable, as predicted. This pattern of results indicates that adolescents with autism integrate visual cues to 3D structure in the same way as typically developing adolescents.

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56.510 Gaze and preference decision making in autism

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Preference and gaze interact in a positive feedback loop to produce a phenomenon known as the 'gaze cascade' effect. In the few seconds before a decision is made, a gaze bias occurs toward the stimulus that is eventually chosen. This gaze cascade is especially robust in tasks that involve face preference decisions. Autism is a pervasive developmental disorder where deficits in evaluating and making social judgments about faces occur. Persons with autism typically have inattention to faces and direct gaze aversion. The present study was set up to examine whether these known aberrations in visual face processing interfere with preference choice decision making in ASD, reflected in a deviant gaze cascade pattern.

4 ASD subjects and 3 age and gender matched healthy controls (HC) performed a 2-alternative forced-choice task, while their eye-gaze was tracked. Their task was to select the stimulus they prefer by pressing a button under a free viewing condition. Stimulus types consisted of faces and natural scenes.

First, we were able to replicate the findings of a gaze cascade in the HCs, already with this temporary group size. Interestingly, the known gaze aversion for faces in ASD did not interfere with the gaze bias toward the to-be-chosen picture at decision time, independent of stimulus type. Indeed, the probability of a gaze bias towards the chosen picture at 40 ms before response was even significantly higher in the autism group than in the HCs ($p < 0.001$ for each of the conditions). On the other hand, the course of their viewing patterns clearly deviated from that of the HCs and is not in agreement with the typical gaze cascade. These findings implicate that while gaze is clearly involved in preference formation in autistic subjects, the psychological process that leads to the decision may differ from that of HCs.

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56.511 Biological motion perception among persons with schizophrenia

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People with schizophrenia (SCZ) show alterations in several domains of visual processing, including visual motion processing. However, less is known about biological motion perception among persons with SCZ. Such knowledge is important because humans utilize biological motion for understanding socio-emotional aspects (e.g., intentions) of actors in their environment and people with SCZ are well known to have deficiencies in this area. In the current study, groups of healthy community based controls (N=20) and patients with SCZ (N=16) were asked to discriminate the direction of motion of four types of point-light walkers: upright normal walkers, inverted normal walkers, upright scrambled walkers (which contained only local motion information), and upright random-position walkers (which contained only global form information). Normal and inverted walkers were also presented in a dynamic random noise mask. Both groups of observers were able to accurately discriminate the direction of motion of normal and inverted walkers when presented without the mask. However, performance in SCZ participants was significantly lower than that of healthy observers when the stimuli were presented in the mask. Additionally, although both healthy and SCZ participants performed accurately when observing random position walkers, both groups also performed less accurately when observing scrambled walkers. The results suggest that, like healthy observers, people with SCZ rely more on global form rather than local motion in making direction discriminations of biological motion. These results also suggest that people with SCZ are able to discriminate the direction of biological motion of normal and inverted walkers; however, they are less efficient than healthy observers at extracting the relevant motion signal from noise, consistent with the notion that people with SCZ suffer from more noisy perceptual systems.

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Object recognition: Categories

Tuesday, May 10, 3:00 - 7:00 pm

Vista Ballroom, Poster Boards 512 - 529

56.512 Basic-level object categorization of natural scenes in the near-absence of focal attention

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Studies have shown that complex visual scenes can be categorized at the superordinate level (e.g., animal/non-animal or vehicle/non-vehicle) with minimal attentional requirements. Retrieving finer-grained information in order to perform basic-level categorization of natural scenes, such as dog/non-dog or car/non-car, requires additional processing (i.e., reaction times are longer) and might thus involve attentional processing. The attentional requirements of basic-level categorization of natural scenes were tested in the current study with a dual-task paradigm in which subjects performed the basic level categorization task either alone (single task condition) or concurrently with an attentionally demanding letter discrimination task (dual task condition). To determine whether basic level categorization can be performed outside the spatial focus of attention we compared accuracy on this task in the single task condition (when attention is available) and the dual-task condition (when attention is engaged by the letter discrimination task). If the basic-level categorization task does not require attention then performance on this task in the single and dual task conditions should be comparable. However, performance in the dual task condition should be considerably impaired if attention is necessary for successful categorization at the basic level. Our results indicate that basic-level categorization of biological (dog/non-dog) and man-made (car/non-car) stimuli can be performed remarkably well even when attention is not fully available. However, categorization at the basic level entailed longer stimulus presentation times than at the superordinate level, reflecting an increase in the amount of information required. Thus, although basic-level processing involves longer stimulus presentation durations and results in longer reaction times compared to superordinate-level processing, it can still be performed in the near-absence of attention.

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56.513 Rapid visual categorization of objects in natural scenes: the "contextual effect" is strengthened by aging

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The processing of objects embedded in an incongruent context, is impaired in accuracy and speed. This "contextual effect" is observed even when top-down influences are minimized by using rapid visual categorization of briefly flashed scenes. This effect could result from feed-forward interactions between selective populations of visual neurons: facilitation (interference) would result from habitual (conflictual) co-activations. In the present study, we investigated whether the size of the contextual effect was modulated as a function of age. We tested 87 subjects (20-91 years old) in a two forced-choice rapid categorization task. Images containing either an animal or a piece of furniture in congruent or incongruent context were briefly flashed on a screen. Participants were asked to categorize the object by responding as fast as possible using two buttons (each button being assigned to one category). Performance was analyzed separately depending on age. Four groups were considered: 20-30; 45-55; 60-75 and over 75 years old. A bank of images was specifically created for this task, with objects of variable size (mean size = $12.7 \pm 4.7\%$ of total pixels) as an anticipation to tackle pathological aging, and a strict control of luminance, contrast, object size and localization. As already reported, contextual incongruence impaired object categorization in both accuracy ($p < 0.001$) and response speed ($p < 0.001$). The present study shows that this effect increases progressively with age ($p < 0.001$ for accuracy and $p < 0.01$ for speed). Comparing performance on congruent vs incongruent stimuli in the youngest and the oldest group, the drop of accuracy increased from 1.5% to 7% and the mean reaction time from 12ms to 30ms. Inhibitory or facilitatory co-activations

between visually selective populations of neurons are expected to be built from experience. The enhancement of the contextual effect in healthy aging could be due to a lifetime of experience with the surrounding world.

56.514 Scanning parameters for optimal decoding in visual cortex using a 32-channel head coil for fMRI

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Our goal was to assess the increase in sensitivity afforded by a new Philips 32-channel head coil for decoding brain states associated with viewing natural images. Data collected with the 32-channel coil were compared to a dataset collected previously using an 8-channel coil. The stimuli for the study included images of 6 animal species including 2 primates, 2 birds, and 2 insects. We tested three scanning protocols to assess trade offs between signal-to-noise ratio (SNR), voxel size, and brain coverage using multivariate pattern (MVP) classification and similarity analysis as dependent measures. Condition 1 (3 mm isotropic voxels, SENSE 2) provided the largest SNR and the most brain coverage (105 mm inferior to superior, I-S), but the lowest resolution. Condition 2 (2 mm, SENSE 2) provided better resolution, but smaller SNR and the least brain coverage (50 mm I-S). Condition 3 (2 mm, SENSE 3) provided better brain coverage (66 mm I-S) than condition 2, but further decreased the SNR. All three protocols used TR of 2 sec, which matched that in the original study (8-channel coil; 3mm, SENSE 2). We assess results within anatomical masks in ventral temporal (VT) and early visual cortex (EV). Classification results in both VT and EV show that condition 3 performs worse than the other conditions, most likely due to decreased SNR associated with higher SENSE. Classification measures in VT indicate comparable performance for conditions 1 and 2, while in EV there is an appreciable boost in performance for condition 2, which is maximized at lower levels of spatial smoothing. This finding is consistent with the characteristic of the 32-channel coil that it provides higher signal especially at the periphery of the scanning volume. Thus studies targeting peripheral brain structures stand to benefit most from the increased signal provided by the 32-channel coil.

56.515 Visual representations of temporal context

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When taking a detour on the way home, does the visual system treat the front of your house differently than when you take the normal route? In the study of vision, representations are believed to reflect the physical attributes of the current stimulus. In contrast, in the study of memory, representations contain not only current stimulus features, but also a moving window of recent experience (temporal context). Here we test whether representations in high-level visual cortex contain temporal context information. In a jittered event-related fMRI design, eighteen observers viewed a series of scenes presented one at a time while making orthogonal indoor/outdoor judgments. Several scenes were repeated once over the course of each scanning run, but, unbeknownst to observers, some repetitions were preceded by the same two scenes in the trial sequence as when they were initially encountered (repeated context) and others by two novel scenes (novel context). To measure the effect of context, we examined repetition attenuation in the parahippocampal place area (PPA). If the PPA learns temporal context (in one shot), then scenes repeated in context will be more similar to the stored representation and will elicit greater attenuation. As a baseline, scenes repeated in novel contexts elicited significant but weak attenuation compared to when they were novel, but only in right PPA. In contrast, scenes repeated in repeated contexts elicited robust attenuation in bilateral PPA compared to when they were novel, and this effect was significantly stronger than for novel context repeats. A control study with eight new observers demonstrated that this context-dependent attenuation does not reflect carryover from repeated contexts per se, since presenting novel scenes in repeated contexts eliminated all traces of attenuation. While featured prominently in episodic memory, our findings suggest a broader role for temporal context in determining the content of perceptual representations.

56.516 The neural basis of rapid visual recognition: Neural decoding and Granger causality analysis of connectivity.

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A visual paradigm that has been extensively used to study visual cognition is the rapid categorization paradigm (Thorpe et al, 1996). While much is known about its psychophysical basis, its neural underpinnings still remain to be understood. Here we recorded intracranial field potentials (IFPs) from the occipital and temporal lobes of human patients implanted with subdural electrodes while they were engaged in a rapid animal categorization task.

Using multivariate pattern analysis techniques, we quantified at millisecond precision the amount of visual category information conveyed by IFPs. Our analysis, which suggests that abstract category information can be read-out at a level close to behavioral performance (typically within the 70-80% accuracy range), includes the estimated flow of visual information and a lower bound of the read-out latencies. Additional results using spectral properties of the signal suggest a substantial amount of task relevant information in the delta phase and alpha amplitude that is seen selectively in the regions along the ventral stream. By quantifying the information content using the neural decoding, we investigated the relationship between electrode selectivity to category and behavioral measures in a correlation analysis.

We also employed Granger causality as a measure of connectivity during the task. This measure combined with multivariate autoregressive models was used to explain the causal interactions between the recording sites by means of revealing how a past state of a brain region informs the current state of another. Partial causality and spectral causality measures were also used over successive time windows during the task. Linking causal flow along the ventral stream to the neural information content in recording sites, we outline a comprehensive analysis of the connectivity in relation to the visual categorization and the dynamics of re-entrant signals in the low to intermediate parts of the visual system.

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56.517 The Bank of Standardized Stimuli (BOSS): a new normative dataset of 480 visual stimuli to be used in visual cognition research

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The development of digital technology has provided neurocognitive scientists access to very high quality visual stimuli for use as experimental material. Importantly, stimuli are not solely defined by their figural modalities but by other features too (e.g. by how easily they can be named and manipulated or how familiar they are). In research, these features need to be controlled for otherwise they can act as confounding variables that could interfere with performance, for example, making the results more difficult to interpret. However, control of these confounding variables is possible with sets of stimuli that have been normalized. Several normative datasets exist for line-drawings and, only more recently, for photos. The present work proposes the Bank Of Standardized Stimuli (BOSS), a set of 1,460 high quality photos of common objects among which 480 were normalized for name, category, familiarity, visual complexity, object agreement, viewpoint agreement, and manipulability. Of these objects, 209 have more than one exemplar and 386 have been photographed under different viewpoints. Stimuli are also available in greyscale, blurred, scrambled, and line-drawn version. The BOSS proposes ecological stimuli and new norms and was created specifically to meet the needs of scientists in cognition, vision and psycholinguistics.

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56.518 **Integral dimensions can be differentiated in dimensional but not polar morphspaces**

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How does category learning affect visual perception of objects? While there is agreement that category learning improves the ability to later discriminate between objects, there is some debate whether this improvement is selective for relevant object dimensions or not. In prior work (Folstein et al., submitted), we noted that studies finding selective improvements along relevant dimensions used “dimensional” morphspaces, constructed by morphing between separate morphlines defining an x-axis and a y-axis, while studies showing no selective improvements used “polar” morphspaces, created by morphing directly between morphparents. One interpretation of these results is that dimensional spaces have separable dimensions even before any category learning, corresponding to the morphlines used to construct them, while polar spaces have integral dimensions. Another possibility is that both dimensional and polar spaces are have integral dimensions before any category learning, but that category learning causes dimensional spaces to become separable through a process known as differentiation. We first trained participants to categorize objects in dimensional or polar morphspaces according to diagonal or orthogonal category boundaries. Participants were equally accurate in learning diagonal and orthogonal boundaries in both spaces, suggesting that both spaces are initially integral. We next trained those participants to categorize the same spaces according to a new category boundary that was rotated by either 90 degrees or 45 degrees relative to the original boundary. Now learning in the dimensional space was worse when the boundary had been rotated 45 degrees than when it had been rotated 90 degrees, suggesting that the initial category learning caused differentiation into arbitrary separable dimensions orthogonal to the learned category boundary (Goldstone & Steyvers, 2001). In contrast, there was no evidence of differentiation in the polar space. These results provide further evidence that morphspace structure places important constraints on the effect of category learning on visual perception.

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56.519 **Self reference and familiarity in handwriting recognition**

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We studied handwriting recognition in an X-AB task, by asking participants to discriminate if a handwritten target word was produced by the same writer as one of two comparison words, shown in left/right positions. Three types of writers have been considered: self, best friend, stranger. We collected a large sample of handwritten words by 10 pairs of best-friend children, attending 3rd and 5th primary school classes, and tested every child individually after 1 and 2 months, using the following AB pairs: self vs. best friend; self vs. stranger; best friend vs. stranger; stranger vs. another stranger. Therefore, discrimination could benefit from three factors: agency (present only in self handwritings), familiarity (present in self and best-friend, but not stranger, handwritings), and form similarity (differentiating various handwritings). Agency and familiarity effects were revealed by the superiority of performance in trials in which self and best-friend handwritings were compared to stranger handwritings, over those involving the handwritings of two different strangers. Taking discrimination accuracy by stranger participants as a dissimilarity value, we used a multidimensional scaling approach to find the relative distances of the 20 handwritings. Such distances were significantly distorted by agency and familiarity (i.e.; distances were modified when AB pairs involving self and best-friend handwritings were considered). Children data confirmed previous results obtained in our lab with university students, using a similar paradigm, as well as conclusions by Chen et al. (2008) in their study on the identification of Chinese handwritings.

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56.520 **Selection of response candidates during the process of object categorization is based on similarity in intrinsic part structure**

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It is well known that multiple interpretations are activated when an object needs to be categorized. It has been suggested that distinct interpretations may share large similarities in visual appearance. It is not clear, however, which aspect of perceptual similarity is most important for response selection. We therefore investigated the similarity between response candidates by conducting a double-naming experiment. Observers were asked to name two possible interpretations of a morphed figure. Information about the degree of similarity between the objects used for morphing (i.e. extreme objects of a morph series) was previously collected (Hartendorp et al., 2010) for the aspects of shape, number of parts, intrinsic part structure, semantics and phonology. We used this information to reveal which aspect of similarity was shared between the two responses on the double-naming task. The findings showed that two extremes of a morph series showing high similarity on the aspect of intrinsic part structure resulted in morphed figures being interpreted as both the dominant and nondominant object. The other similarity aspects had no influence on the interpretations. We conclude that selection of response candidates is based on similarity in intrinsic part structure. These findings are discussed in terms of the skeletal representation of an object.

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56.521 **A Neural Network Model for the Concurrent Perception of Multiple Objects**

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Many people have the subjective sense of being able to see more than one object at a time. However, given the large receptive fields of neurons in the later stages of the ventral visual pathway, it is unclear how two similar objects could be perceived without interfering with each other. It has been proposed that the concurrent perception of multiple objects is illusory or only explicable through mechanisms such as neural synchrony (von der Malsburg, 1999). Counter to these proposals, we develop a neural network model of object recognition capable of identifying two objects at a time given only the addition of a dorsal attentional component. This mechanism is consistent with findings from Balint’s patients, multi-object tracking, and change detection tasks supporting a role for posterior parietal cortex in the perception of multiple objects.

Our model consists of a ventral pathway, trained to identify objects, and a dorsal pathway, trained to transform visual inputs into potential actions. Dorsal activity emergently represented both object locations and features, consistent with studies that key parietal regions may code for certain object characteristics (e.g. Konen & Kastner, 2008). With the dorsal and ventral pathways connected during training, the network learns to utilize dorsal signals to bias ventral activity towards the correct objects while suppressing errors, allowing the correct simultaneous identification of two objects. We simulate data from illusory conjunction experiments wherein, when two objects are presented briefly, subjects often erroneously report an object which miscombines the features of the actual objects. Simulated dorsal lesions impaired the identification of two objects, with recovery of double-object identification following a similar trajectory as Balint’s patient R.M. In contrast, simulated ventral lesions disrupt object identification but not dorsal functions, similar to visual form agnosia patient D.F., whose ventral pathway damage allowed her to manipulate objects she was unable to identify.

56.522 **Left hemisphere advantage in the visual processing of graspable objects**

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In a series of grasping studies using visual illusions we showed that regardless of handedness, right hand but not left hand grip apertures are accurately scaled to the size of an object. Grip apertures in the left hand, reflected the perceived (illusory) and not the real size of the target (Gonzalez et al 2006, 2008). We advanced the hypothesis that the left hemisphere is specialized for visually-guided grasping and that this specialization was

independent of handedness. Grasping requires the integration of a visual and a motor component, however. Here we investigate if there are hemispheric asymmetries in encoding visual properties of objects that could later explain the left hemisphere/right hand advantages in visually-guided grasping. We presented pictures of graspable objects, defined as objects that could be picked up with one hand (e.g. coin, apple, etc) and non-graspable objects, defined as tangible objects that could not be picked up with one hand (i.e. car, piano, etc) selectively to the right (RVF) or left (LVF) visual fields. Graspable/non-graspable objects and RVF/LVF presentation were randomized over the trials. Right- and left-handed participants quickly pressed a button with the index finger if the object on the screen was of a graspable object and pressed a different button with the middle finger if it was of a non-graspable object. Responding fingers and starting hands were counterbalanced among participants. Overall, reaction times were shorter for graspable objects than for non-graspable objects. Furthermore, there was a RVF (left hemisphere) advantage (shorter reaction times) but only for graspable objects. No visual field difference was detected for non-graspable objects. These findings were the same for right and left-handers. The results strongly suggest that the processing of graspable objects regardless of handedness is more efficient in the left hemisphere and this might help explain asymmetries in visually-guided grasping.

56.523 Activation of visual information by verbal versus nonverbal cues

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Responses to visual stimuli can be altered by cues presented prior to the target. These cues (or primes) can be nonverbal (e.g., an arrow, a color patch) or verbal (i.e., a written or spoken word). However, the possible differences produced by verbal and nonverbal cues on visual processing have been largely ignored. The present work directly compared the efficacy of verbal and nonverbal cues in evoking visual object representations (see also Lupyan & Thompson-Schill, 2010).

Participants completed a series of cue-to-picture matching tasks. Each trial began with an auditory cue and 1 s after cue-offset, a picture appeared that either matched the cue or not. Participants made speeded 'match' or 'mis-match' responses. A random half of the cues were verbal, e.g., "cat," "bowling-ball," "bee," "car." The remaining cues were nonverbal, e.g., a meowing sound, a bowling ball hitting pins, a buzzing bee, a car-honk. All cues were matched in length and offline norming ensured that cues were unambiguous. Yet, object recognition following verbal cues was faster and more accurate than following nonverbal cues. The mean reaction time (RT) difference ranged from 25-60ms and remained unchanged even after extensive training on the task (>400 trials) with as few as 4 object categories.

The verbal cue advantage was significantly larger for pictures depicting objects in typical configurations compared to sound-evoking objects, e.g., a typical dog image versus a dog with an open jaw. This cue-by-image-type interaction was eliminated when high-spatial frequencies were removed from the images; this manipulation did not affect the overall label advantage. In addition, object categorization RTs following a verbal cue strongly correlated with typicality—a classic observation that more typical objects are classified faster. This correlation was absent on nonverbal-cue trials suggesting that verbal labels activate more typical visual object representations than those activated by nonverbal cues.

56.524 Unraveling ultra-rapid categorization

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The classic finding of a basic-level advantage in categorization (Rosch et al., 1976) has been challenged by recent findings in ultra-rapid categorization tasks (Thorpe et al., 1996). Rapid decisions made in a glance suggest that superordinate (e.g., "animal") representations are accessed as fast as or faster than basic (e.g., "bird") representations (Macé et al., 2009; Mack & Palmeri, 2010). The conclusions from classic and rapid categorization are in conflict. That could be because the two different paradigms underlying these conclusions differ on several critical factors.

We attempted to make sense of these contradictory conclusions by investigating both the effect of stimulus exposure and blocking of target categories on the speed and accuracy of categorization decisions. We crossed two different exposure durations (25ms versus 250ms) and two different category orders (blocked versus randomized) across four category verification

experiments where animals and plants were categorized at the superordinate, basic, and subordinate levels. As expected, with brief exposures and blocked target order - conditions typically used in the rapid categorization paradigm - superordinate categorization was as fast and accurate as basic categorization. In contrast, we observed a basic-level advantage in the three other conditions. With a random target order and brief exposures and with longer exposures responses were fastest and most accurate for basic categorization.

These results suggest that the experimental context of rapid categorization may evoke specific processing strategies not found when using what may arguably be considered default categorization strategies. Classic and rapid categorization results may not be in conflict per se. Instead, these two paradigms characterize different aspects of the perceptual categorization system. You may spot the animal faster than the bird, but only at a glance and when finding animals is the only thing on your mind.

56.525 Reentrant Visual Processing Affects Rapid Object Categorization in Natural Scenes

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The human visual system is very fast and efficient at extracting information about objects present in complex natural scenes. For example, Thorpe, Fize, and Marlot (1996) showed that participants were able to decide whether a natural scene contained an animal even when the image was presented briefly. Moreover, Rousselet, Fabre-Thorpe, and Thorpe (2002) used the animal versus non-animal categorization task and showed that participants could reliably indicate the side containing an animal when two images were simultaneously flashed in the left and right hemi-fields. Together, these results suggest that a great deal of visual information is processed in a fast and feedforward way so that object categorization in natural scenes can be achieved rapidly. The current study aimed to examine whether recurrent visual processing plays a role in rapid object categorization in natural scenes by using an object substitution masking paradigm. We had participants perform an object categorization task. On each trial, two images were simultaneously presented for 20 ms in the left and right visual fields; participants then had to indicate whether an animal or a vehicle appeared in the target picture, which was surrounded by eight dots. These dots either disappeared simultaneously with the target and distractor pictures or remained on the screen for 200 ms. According to Di Lollo, Enns, and Rensink (2000), object substitution masking occurs when a lateral mask (e.g., small dots) persists beyond the duration of a target, reflecting reentrant processes in vision. Therefore, the trailing dots should not affect categorization performance if rapid object categorization requires no reentrant processing from higher-level visual areas. However, our results showed that the trailing dots impaired participants' categorization performance, suggesting that reentrant visual processing affects rapid object categorization in natural scenes.

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56.526 Priming of superordinate categorization of object pictures by spatial-frequency filtered versions

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Recent object recognition theories propose an initial fast feedforward sweep to high-level visual areas resulting in a first "interpretation" of the visual input which is then fed back to ongoing bottom-up analysis in low-level ventral visual areas (e.g., Bar, 2003). However, the factors mediating (the degree of) top-down processing necessary for recognition, the nature of this first interpretation, and the time-windows in which they are most effective are still unresolved questions. In the current study, we investigated changes in object recognition processing elicited by top-down interpretations based on spatial-frequency information in the visual input. Participants were asked to perform a superordinate categorization task (natural versus manmade) of grayscale pictures of everyday objects, which were preceded by a high- or a low-spatial-frequency filtered version of either the same or another object. We explored the influence of several factors on the formation of global shape candidates in this priming paradigm. Specifically, processing time of the prime (short versus long) and similarity in shape and/or category between the prime and target picture were

manipulated. Discrete time survival analysis was applied to model the temporal dynamics of the effects (Singer & Willett, 2003). We found an early temporal advantage for categorizing objects when preceded by shape and category congruent primes compared to same category but different shape primes. Critically, low-pass filtered primes did not accelerate the categorization process compared to high-pass filtered primes. Results are interpreted within a dynamic, interactive processing framework. We are currently exploring the influence of these factors using a more demanding identification task, and degraded targets (fragmented object outlines as used in Torfs, Panis, & Wagemans, 2010).

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56.527 The Scene Superiority Effect: Discriminating Objects and Instances

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The word superiority effect refers to the phenomenon in which two letters are easier to discriminate when placed within the context of a real word, even when the word is completely non-predictive of which letter appeared. For instance, people can better discriminate "word" from "work" than they can discriminate "d" from "k." The effect disappears when the letters are placed in a non-word context of random letter strings. We investigated whether a similar contextual benefit for discrimination would occur for objects when they are presented in a scene context. Subjects discriminated between two objects in a two-alternative forced choice paradigm. Objects could appear on one of three possible backgrounds: a semantically consistent scene, a semantically inconsistent scene, or a 100% phase scrambled scene. Much like the word superiority effect paradigm, both target objects were equally consistent with a given background, making the backgrounds uninformative to doing the main task. Regardless, subjects still demonstrated a benefit for discriminating between two objects on a semantically consistent background compared to a semantically inconsistent background. Further experiments explored the mechanism behind the benefit. In order to test whether the effect of a semantically consistent background on object discrimination was the result of perceptual enhancement for the semantically consistent objects, we repeated the experiment using different instances of the same object (e.g., two different alarm clocks). Data for discriminating between instances of the same object differ from those for discriminating between two different objects, suggesting a different mechanism for the effect.

56.528 The effect of eccentricity on working memory for different object categories

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Levy and her colleagues (2001) found face-selective regions were more activated when faces were presented in the central field than in the peripheral field, while opposite trend was found for place-selective regions. However, because they did not investigate behavioral consequences of this center-periphery organization, we investigated whether this organization influenced performance in working memory tasks depending on object categories. In Experiment 1, participants performed a change detection task. Stimuli were presented in 2.5°~4.5° in the center condition, and in 11.5°~20° in the periphery condition. In each trial, either 2, 3, or 5 faces or buildings were simultaneously presented for 500 ms. After 1 sec delay, the test display was presented. In this display, single object could change into another object in half of the trials. Participants reported whether one of objects had changed. We found d-prime of face-change detection decreased in the periphery condition, whereas d-prime of building-change detection increased, as the task became more difficult. Furthermore, when faces were presented in the periphery, participants used more conservative criteria than in the central field. However, the opposite pattern was observed for buildings. In Experiment 2, we used a serial memory scan task and added the fovea condition (1.8°). In each trial, the RSVP stream, which consisted of 4 faces or buildings with 2 irrelevant objects, was presented. Each object was presented for 200 ms with 100 ms of ISI. After a delay of 1 sec, a target appeared. Participants reported whether the target was in the RSVP stream. The results showed that d-prime of face-search task decreased with eccentricities, whereas that of building-search task did not change. These results

suggest that working memory for faces is better in central vision and working memory for buildings is better in peripheral vision, which is consistent with Levy et al. (2001)'s findings.

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56.529 Higher-order image statistics is a cue for animal detection

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We can rapidly judge whether images of natural scenes contain animals or not (Thorpe, Fize and Marlot, 1996). So what information do we utilize to rapid animal detection? Image statistics could be a candidate for the task. For example, Torralba & Oliva (2003) found that Fourier amplitude spectra of images potentially predicted the presence/absence of animals. Nevertheless, for humans, it remains unclear which statistics are important to detect animals. Behavioral studies suggested that human observers are unlikely to utilize amplitude information on its own (Wichmann et al., 2010). We investigated whether higher-order image statistics proposed by the texture synthesis algorithm of Portilla and Simoncelli (2000) could be a cue for animal detection. These statistics are likely to be essential for human texture perception under brief viewing (Balas, 2006), so we hypothesized that the statistics also would contribute to animal detection. In Experiment 1, we compared detection performance between three types of distracter images: synthesized textures which shared statistics with animal images of natural scenes, synthesized textures having the same statistics as non-animal images and non-animal images themselves. Participants had to detect animals in pictures with brief presentation (40ms) as quickly and as accurately as possible in the Yes/No paradigm. On each trial, a single image was located on the fixation point (0deg) or at the eccentricity of 14 deg. The detection performance was significantly lower when texture images sharing the statistics with animal images were used as distracter than other distracter conditions at both eccentricities. In Experiment 2, we carried out the same task using new images with their amplitude equalized. The result ruled out the possibility that amplitude difference between animal and non-animal image sets cause the performance impairment. These findings suggest that humans make use of higher-order statistics for rapid animal detection.

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Object recognition: Features

Tuesday, May 10, 3:00 - 7:00 pm

Vista Ballroom, Poster Boards 530 - 548

56.530 Micro-Valence: Nominally neutral visual objects have affective valence

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While some visual objects prompt strong affective responses (e.g., guns and ice cream), most objects are thought to be affectively neutral. Last year we reported evidence for the existence of "micro-valences" (Lebrecht & Tarr, VSS, 2010): that nominally neutral objects actually possess subtle valences that we hypothesize form an integral part of object perception. In the current experiment we used fMRI to investigate: a) the extent to which micro-valences are coded within the extended visual object recognition network (Bar, 2007); b) how micro-valences are neurally instantiated with respect to valence strength and direction. Using slow event-related fMRI, participants viewed an object picture for 500ms and evaluated the object's "pleasantness" on each trial. Participants were shown 120 everyday, nominally neutral objects (e.g., teapots and clocks) and 120 strongly valenced objects (e.g., gold and a skull). Objects were assigned to these conditions based on mean valence ratings acquired in a prior experiment with a different population of participants. Individualized ratings for all objects were also acquired for our fMRI participants during a post-scan session. Regions of interest for further analysis were identified using two independent localizers: a)

objects versus scrambled objects; b) strongly valenced objects versus minimally valenced objects (e.g., paperclips). Two results stand out. First, somewhat consistent with previous findings, lateral regions of PFC and regions of medial OFC are selective to a positive versus negative comparison for strongly valenced objects. Second, and intriguingly, almost all participants show selectivity for micro-valence objects, comparing positive to negative, in a region adjacent to the region for strongly valenced objects. We posit that intrinsic to visual object perception, object valence – for all objects – is evaluated in PFC. This valence metric forms one of many associated object properties that can influence subsequent perceptual and non-perceptual object-related processing.

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56.531 Unraveling the visual and semantic components of object representation

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Object perception recruits a cortical network that encodes both visual and non-visual properties. Of particular interest is the degree to which perceptual representations of objects are tied to semantic knowledge. Prior studies examining the neural representation of conceptual knowledge of objects have not always dissociated perceptual and non-perceptual components, but instead attribute “neurosemantics” to both visual and non-visual cortical areas (Just et al., 2010; Mitchell et al., 2008). Here we used fMRI to unravel these two components by contrasting voxel population responses for 60 object pictures to voxel population responses for 60 written nouns corresponding to the same objects. BOLD responses in the ventral temporal cortex were analyzed using multi-voxel pattern analysis (MVPA) and a searchlight procedure (e.g., Kriegeskorte et al., 2007). These analyses provide, for both the picture and the word conditions, a matrix of neural dissimilarities between stimulus pairs drawn from all 60 items. This comparison allowed us to directly assess the degree to which non-visual inputs specifying visual objects recruit visual representations. Critically, we were also interested in the featural dimensions underlying these neural codes for objects. To accomplish this we developed multiple models of visual object similarity - ranging from pixel-wise comparisons to distances in feature spaces employed in computer vision - and predicted the structure of the neural responses for both the picture and the word conditions. Although we were able to reliably identify different neural activation patterns for the two conditions, none of our implemented models of visual object similarity provided a close match with BOLD activation patterns past occipital regions. Alternatively, we obtained better data-driven intuitions about the features underlying our neural dissimilarity matrices through two methods: by learning linear filter models of individual voxels; and by image clustering based on the multi-voxel dissimilarity matrices themselves.

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56.532 Viewpoint and Exemplar Generalization in Visual Prediction

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Efficient visual recognition appears to be facilitated by integration of top-down and bottom-up processes. According to a top-down facilitation model (Bar et al., 2006), low spatial frequencies (LSF) are rapidly extracted from early visual areas and projected to the orbitofrontal cortex to generate top-down predictions about potential object identity. Because top-down predictions are proposed to be derived from LSF, it is hypothesized that the same predictions may be activated for inputs that differ to some extent in appearance, such as objects that are viewed from different orientations, or different exemplars from a category. Here we examined how LSF and high spatial frequencies (HSF) facilitate recognition by manipulating viewpoint and similarity using a repetition-priming paradigm. The briefly presented

(30-150ms) prime object was either LSF- or HSF-filtered, followed by a mask, then an intact target object. RT for target recognition was faster when the prime and target showed identical compared with different instances, in both LSF and HSF conditions. While the priming effects increased with longer exposure duration of the prime, the magnitude of the effects was comparable across depth rotations (up to 60°) at all time points, suggesting that multiple representations of objects across viewpoint may be triggered during early processing (Experiment 1). Experiment 2 revealed comparable priming for LSF when the prime and target showed the same item or a similar exemplar from the same category but not when the two exemplars had distinct visual appearance. For HSF, however, stronger priming was obtained for the exact item than for a visually similar item. Consistent with the top-down model, these results suggest that while both LSF and HSF may support viewpoint-general representations during initial processing, LSF is critical in activating a small set of probable interpretations of the input that may fit multiple similar objects and/or objects seen from multiple viewpoints.

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56.533 The word length effect in virtual hemianopia, real hemianopia, and alexia

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Background: A characteristic feature of pure alexia is the word-length effect, in which reading speed increases with increasing word length. However, many alexic patients also have right hemianopia, which can itself cause a hemianopic dyslexia. The degree to which hemianopia causes a word-length effect is therefore an important question. Objective: Our goal was to determine if a word-length effect could be generated under hemianopic conditions in the absence of damage to language processing areas. Method: 13 healthy adults read single words of 3 to 9 letters in length while eye movements were monitored with full-field viewing and then with gaze-contingent displays simulating right or left hemianopia. We also studied 6 patients with reading problems: two had hemianopic dyslexia without fusiform lesions, four had fusiform lesions causing alexia, two of which had associated hemianopia while two had full visual fields. Results: In healthy subjects, there was a small word-length effect with full-field viewing of 14ms/letter, which more than doubled to 37ms/letter for right and 31ms/letter for left hemianopia. The upper 95% prediction limit was 51ms/letter for full-field viewing and 160ms/letter for right hemianopia. These results were corroborated by our patient sample. Our two patients with hemianopic dyslexia fell within the virtual hemianopic range (18.9, 95.1 ms/letter), while the two patients with fusiform lesions causing alexia and hemianopia had word-length effects well beyond this range (1536, 16500ms/letter). The subjects with alexia without hemianopia had modest word-length effects that were abnormal compared to full-field viewing (53, 182 ms/letter). Conclusions: Hemianopic simulations show a small word-length effect of up to 160ms/letter. Given that word-length effects of similar magnitude can be seen in alexia without hemianopia, in patients with hemifield loss in the central 5°, word-length effects should be larger before concluding that there is an additional component of alexia.

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56.534 Greater Sensitivity to Nonaccidental than Metric Differences in Relations

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Behavioral studies and single cell recordings in monkey IT have shown that there is greater sensitivity to nonaccidental property (e.g., straight versus curved), than metric property (e.g., curved versus more curved) changes of simple shapes (Biederman, et al., 2009; Kayaert, et al., 2003). Are we similarly more sensitive to nonaccidental (NAP) than metric (MP) differences in the relations between objects? We generated a set of stimulus triplets that could, from a base stimulus (e.g., a cylinder separated from a brick), undergo a NAP relational change (e.g., the cylinder attached to the brick) or a MP relational change (e.g., the cylinder further separated from the brick).

Critically both relational variations were matched in physical dissimilarity using the Gabor-jet system (Lades et al., 1993), a model of V1 similarity. In an adaptive staircase match-to-sample paradigm, a target stimulus was presented with two samples, one of which was an identical match and the other, a distractor that varied in either a NAP or MP change. To achieve 75% accuracy, subjects required more than double the amount of presentation duration for detecting differences for MP (795 ms) than for NAP (330ms) relational changes. The results could not be explained by differences in local or global features. Given recent findings that the lateral occipital complex (LOC) is a critical region for the coding of relations between objects (Kim & Biederman, in press) and within parts of an object (Behrmann et al., 2006), a prediction is that the differential sensitivity of NAP vs. MP relational changes likely arises in LOC as well.

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56.535 **The Benefit of Scene-Like Interactions on Object Identification Arises in LO Rather than Being a Consequence of Parietal Attentional Modulation**

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Our visual experience is generally not of isolated objects, but of scenes, where multiple objects are interacting. Such interactions (e.g., a watering can positioned to pour water onto a plant) have been shown to facilitate object identification compared to when the objects are depicted as not interacting (e.g., a watering can positioned so that it is pouring away from the plant) (Green & Hummel, 2006). Where is the neural locus for this advantage? The lateral occipital cortex (LO), the first cortical region where intact shape is distinguished from texture (Malach et al., 1995; Cant & Goodale, 2007), is the same area that shows greater responses to object pairs depicted as interacting compared to when they are not interacting (Kim & Biederman, in press; Roberts & Humphreys, 2010). However it is possible that the intraparietal sulcus (IPS), engaged by attentional demands (e.g., Kanwisher & Wojciulik, 2000), modulates the activity in LO. To test this hypothesis, we delivered transcranial magnetic stimulation (TMS) to LO and IPS while subjects detected a target object that was or was not interacting with another object to form a scene. TMS delivered to LO but not IPS abolished the facilitation of object identification for interacting objects compared to non-interacting depictions observed in the absence of TMS, suggesting that it is LO and not IPS that is critical in the coding of object interactions.

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56.536 **Extrinsic reference frames modify the neural encoding of object locations during active spatial navigation**

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The ability to form object-to-object spatial representations is an important component of successful spatial navigation. Retrieval of object-location information is more efficient and accurate when an observer's heading within an object-array is aligned with an extrinsic reference frame (e.g., parallel to the sides of a rectangular field), than when it is misaligned (e.g., a heading that runs oblique to the field's side). Whether this alignment effect is due to stronger stored representations for aligned views or differences in egocentric-transformation processes during retrieval is unknown. We used functional magnetic resonance imaging (fMRI) to address this question. In an initial encoding phase conducted outside the scanner, participants learned the layout of an object array in an active virtual-navigation paradigm. A square mat positioned on the floor of the virtual arena acted as the extrinsic reference frame. A subsequent retrieval phase was conducted in the scanner, during which participants performed a spatial judgment task that required them to imagine orientations of the learned object-array that were either aligned or misaligned with the sides of the mat. Consistent with previous findings, participants responded faster and more accurately when the imagined orientation was aligned as opposed to misaligned with the extrinsic reference frame. Analysis of the fMRI data also revealed significant differences in brain activity between the two conditions. For the Aligned>Misaligned contrast, significantly greater activity was observed bilaterally in the inferior occipital, inferior and middle temporal, and fusiform gyri. For the Misaligned>Aligned contrast, significantly greater activity

was found bilaterally in dorsolateral prefrontal and anterior cingulate cortex, and in the right anterior prefrontal and anterior insular cortex. The activation of distinct neural circuits for the aligned and misaligned conditions during object-location retrieval suggests that extrinsic reference frames modulate the way in which object-location information is encoded during active spatial navigation.

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56.537 **Different temporal dynamics of topological and projective geometrical perceptions in primary visual cortex: a TMS study**

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Accumulating behavioral evidence suggested that global topological properties are extracted at the very beginning of visual processing. However, neuroimaging studies found that topological perception mainly activated the anterior temporal lobe (ATL), which lies in the late destination of ventral visual pathway. There seems a contradiction. To reconcile the behavioral findings with neurophysiology and anatomy of topological perception, we hypothesized that topological properties may be processed via a rapid subcortical shortcut to ATL, bypassing V1. We tested this prediction by applying transcranial magnetic stimulation (TMS) over V1 in an odd quadrant task. In the odd quadrant task, all four quadrants each contained a figure, and subjects were asked to report whether a quadrant differs from the other three. The disparate quadrant differs from the rest either in projective properties (e.g., disk vs. solid parallelogram) or in topological properties ('hole' vs. 'no-hole' figure). The single-pulse TMS was applied over occipital pole at different SOAs (-30 ~ 300 ms). Consistent with previous findings, the data revealed two vital temporal phases for visual discrimination based on projective differences. The discrimination performance (d') declined significantly when V1 was disrupted at SOA of 30 ms (early) and 150 ms (late). This early phase usually reflects that feedforward processing of visual information travel through the early subcortical stages of the retino-geniculo-striate pathway and arrives at V1. The late phase usually reflects the feedback modulation of higher cortical areas to V1 and is vital for arousal and consciousness. However, only a late phase was revealed for all kinds of topological discrimination. Disruption of V1 at early time did not affect topological discrimination. Thus, the results provided the direct evidence that topological perception does not necessarily depend on the initial processing at V1 and may be mediated via a rapid subcortical pathway to ATL, bypassing V1.

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56.538 **The composition of context: assessing the contribution of different types of scene information in visual object recognition**

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The contextual scene in which an object appears can provide critical information for identifying that object. In previous studies, Barenholtz (VSS, 2009) found that participants could identify objects on the basis of reduced visual information when those objects appeared in context than when they appeared in isolation. The current study assessed the contribution of different sources of information available in a contextual scene. We compared performance—as measured by the level of resolution needed for recognition—across five contextual preview conditions: 1) General Scene, in which subjects first saw a preview of the contextual scene in which the object had originally appeared (the target object was digitally removed from the image in all of the preview scenes); 2) Object Location, in which the preview of the scene also included a cue to the location of the object; 3) Object Size, in which the preview was followed by a size referent; 4) Object Location and Size which combined conditions 2 and 3 and 5) No Context, in which there was no scene preview. We considered each of these different contextual conditions for both 'Experts' (where the scene stimuli were drawn from photographs of their own homes) vs. 'Novices' participants, who were not familiar with the scenes. Some of the major findings included an effect of expertise across all context conditions; Experts, but not Novices, showed significant benefits from location information; a strong deficit in the no-

context condition for both Expertise groups. In additional analyses, we included independently obtained ratings of the target objects along several dimensions including the consistency of the object type within the scene category, the frequency of such object-types in those scenes and the typicality of the particular object as an example of that object-type. In general, higher consistency ratings were most strongly correlated with improved performance.

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56.539 Diagnostic features are prominent in object representations

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Question: Does our representation of a learned object weigh all features equally or are diagnostic features given greater prominence? To find out, we conducted a visual search experiment based on the premise that search will be fastest when the features that are prominent in the observer's representation are also salient in the stimulus.

Methods: Observers were trained to associate names with three butterflies that had different types of texture on their upper and lower wings. For each observer, the texture sample on one set of wings varied (the diagnostic wings) while the texture sample on the other set of wings was fixed (the common wings). Soon after training, the observers were tested on a visual search task with the butterfly names as cues. Each search stimulus contained one butterfly on a textured background; the observer's task was to locate the butterfly. On some trials, the statistics of the background texture matched those of the common wings, causing the common features to be highly camouflaged and the diagnostic features to be salient. On other trials, the statistics of the background texture matched those of the diagnostic wings, causing the diagnostic features to be highly camouflaged and the common features to be salient.

Predictions: If diagnostic features are given special prominence in object representations, then search should be fastest when those features are salient in the image. If common features are given special prominence (possibly because they are seen most frequently), then search should be fastest when those features are salient in the image.

Results: Observers found butterflies faster on background textures that camouflaged the common wings rather than the diagnostic wings. Our internal representation of objects gives greater prominence to diagnostic features than to common features.

56.540 Attention is Directed to Distinguishing Features During Object Recognition

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Research on object recognition has focused mainly on bottom-up processes that analyze the visual input; the potential role of top-down processes has been relatively neglected. We propose a framework that views object recognition as discrimination between probable alternatives—an iterative process in which bottom-up and top-down processes interact, and in which attention plays a critical role. Although elements of this framework have been discussed by others, to our knowledge this is the first attempt to test these ideas empirically. A series of experiments tested the basic hypothesis derived from this framework: In the course of object recognition attention is directed to distinguishing features—features that are the most informative and diagnostic of object identity in a particular context. Observers discriminated between artificial fish that differed in one distinguishing feature, such as mouth or tail-fin (in separate conditions). Differences in the allocation of attention to distinguishing and non-distinguishing features were examined using primed-matching tasks (Experiments 1, 2), in which identity matching of two target figures is faster if similar stimuli have previously been attended than if they have not, and using visual-probe and spatial-cueing tasks (Experiment 3, 4), in which visual processing at a specific location is enhanced when attention is allocated to that location. The results showed that (1) both global and local distinguishing features yielded a greater amount of priming than non-distinguishing features; (2) detection of a visual probe was more accurate when the probe appeared near the location of a distinguishing feature than near the location of a non-distinguishing feature; (3) object (fish) recognition was faster when attention was pre-allo-

cated to the location of a distinguishing feature than to the location of a non-distinguishing feature. These results support the hypothesis that attention is allocated to distinguishing features during object recognition.

56.541 Dorsal stream involvement in object recognition with temporal salience, but not when temporal salience is reduced.

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The 'magnocellular advantage' model of visual processing¹ suggests that the faster magnocellular inputs to V1 allow a rapid dorsal stream activation of parietofrontal attentional processing. This exogenously driven attention system is argued to be activated prior to, and in order to facilitate, object recognition through the ventral stream. We therefore investigated stimuli with or without temporal salience to test whether dorsal stream functioning is differentially involved in such stimuli. This was achieved by measuring contrast sensitivity for two object recognition tasks. In the Abrupt onset task, peak contrast was abruptly presented for 50ms (temporal salience). In the Ramped onset task, contrast increased linearly over 163ms to a peak contrast and then ramped off over 163ms (reduced temporal salience). Motion coherence detection thresholds were used to divide participants into groups of good and poor dorsal stream functioning groups. Although all participants had normal intelligence and visual acuity, the good motion coherence group showed superior performance on the Abrupt Onset task compared with the poor motion coherence group. Groups did not differ on the Ramped Onset task. We suggest that rapid dorsal stream activation is important for initiating attentional processes when a visual stimulus shows temporal salience. By comparison, when temporal salience is reduced, stimuli do not efficiently/effectively activate dorsal stream attention mechanisms prior to object processing in the ventral stream. ¹ Laycock, Crewther & Crewther (2007), *Neurosci & Biobehav Rev*, 31,363-376

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56.542 How well do you know the back of your hand? Reaction time to identify a rotated hand silhouette depends on whether it is interpreted as a palm or back view.

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The reaction time (RT) to identify whether an image is of a left or right hand depends on its orientation. Observers mentally rotate the image into a canonical orientation before making their decision. The kinesthetic hypothesis proposes that the RT reflects physiological constraints as if observers actually rotated their hands (Parsons, *J Exp Psychol*, 1994, 20: 709; Fiorio et al., *Brain*, 2006, 129:47). To distinguish this hypothesis from a purely visual transform we used silhouettes of hands which could be interpreted as palms or back views – identical images with different physiological constraints. Silhouettes of left and right hands were generated from a single image, mirror imaged and randomly rotated to one of six orientations from 90° (fingers rightwards) through 180° (fingers down) to 270° (fingers leftwards) and viewed through a circular shroud. Fourteen right-hand-dominant observers were tested in two order-counterbalanced conditions. In condition one, observers were instructed that the images were the backs of hands; in condition two they were instructed that they were palms. Their task was to report as quickly and as accurately as possible whether the presented image was a left or right hand using vertically separated key presses. RTs were measured. The canonical positions of the two hands tilted inwards and also depended on view. For hand images presented at 90° and 270° there were significant interactions dependent on the interpreted view: identical stimuli showed different RTs depending on whether observers were instructed that the image was a right or left hand. For intermediate orientations (130° through 230°) a more complex pattern emerged with effects of view (palm/back) and laterality (left/right). Our pattern of results broadly supports the kinesthetic hypothesis. However, RT is also influenced by image orientation interacting with hand laterality and how the image is interpreted.

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56.543 Stimulus Similarity and Dimensionality in the Processing of Non-Face Objects

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Absolute identification is limited to 7 ± 2 unidimensional exemplars (Miller 1956). While neither practice nor increased gamut removes the limit, multidimensional exemplars do (Shiffrin & Nosofsky, 1994). We have recently shown P200 evoked potential amplitude indexes the visual dissimilarity of sequential stimuli drawn from a linear morphed continuum of 5 faces (Kahn et al, 2010, JOV). We hypothesize that the neural dissimilarity of stimuli of the same physical difference will be ameliorated in the presence of 9 linear exemplars, and restored with 9 exemplars drawn from two dimensions.

We designed a two dimensional stimulus space of radial frequency contours. We selected 5 and 9 exemplar linear subsets (5L and 9L) of these stimuli—with each subset having equal spacing between the exemplars—as well as a two-dimensional, 9 exemplar set (9S) in which the diagonal spacing between the stimuli was equal to that of the linear spaces. Subjects viewed the stimuli (blocked by exemplar space) in a continuous, counter-balanced stream (1s per stim with ITI of 250-350ms) while they monitored for the infrequent appearance of a target stimulus from outside the space. 128 channel ERP was recorded and electrodes responsive to formed visual stimuli were identified in a separate localizer study.

In preliminary data from 3 subjects, we have confirmed that the P200 is modulated by the perceptual similarity of sequential stimuli in the 5L space, extending our previous result to non-face stimuli. This modulation is disrupted in the 9L space and reformed in the 9S space, despite the smaller physical difference between the stimuli. Further analyses will examine the representation of prototype within these spaces. We interpret these results within the context of a flexible model of neural tuning, sensitive to the gamut and distribution of stimulus context.

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56.544 Misbinding of color and motion: Effect of color variation and solidity of object

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BACKGROUND: Visual features of objects in the peripheral region can be mistakenly perceived to possess the features of objects in the central visual field (misbinding of visual features). This misbinding seems to arise from the ambiguity of visual features in the peripheral region (Wu, Kanai, & Shimojo, Nature 2004). We asked whether increased ambiguity in the peripheral region increased the frequency of misbinding of color and motion by manipulating the color variation and solidity of visual objects. Specifically, we varied the color of objects along the L/(L+M) axis (appears roughly red and green) or along the S/(L+M) axis. We hypothesized that misbinding would occur more frequently when the color was varied along the S/(L+M) axis than along the L/(L+M) axis because the mechanism that mediates the S/(L+M) system has lower spatial acuity, leading to more ambiguity in the peripheral fields. In a separate experiment, we used solid objects and hollow objects. We expected to observe more misbinding with hollow objects than with solid objects because hollow objects will impose more ambiguity particularly in the peripheral region. **METHODS:** In the central field, randomly placed objects of one color (e.g., red) moved upward and of another color (e.g., green) moved downward. In the flanking peripheral fields, randomly placed red objects moved downward and green objects moved upward. The observer's tasks were to report the direction of motion of the peripheral red objects and the peripheral green objects. The wrong response was counted as the occurrence of misbinding. **RESULTS & CONCLUSION:** We found more frequent misbinding responses when the color was varied along the S/(L+M) axis rather than along the L/(L+M) axis, and when the objects were hollow rather than solid. Both results support our hypotheses, indicating that the ambiguity in the peripheral region indeed facilitates misbinding of color and motion.

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56.545 Constraints on object perception influence assimilation of objects into the body representation

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Previous studies have shown that grasped objects are rapidly assimilated into the representation of the body. Object assimilation requires the brain to acquire structural properties of the object, which can be acquired through multiple sensory modalities (e.g. haptic exploration). The present study investigated the role of vision in acquiring an object's structure. Our experiments investigated whether visual features that are "perceived" as a whole object would be assimilated as single structural unit. The experiment was a 2 x 2 design using whole objects or discontinuous object parts, which were either displayed in full view of the observer or partially occluded. Importantly, when participants viewed the discontinuous object parts behind the occluder they appeared to be whole object. We used a paradigm, which employs positive afterimages, as a means to assess the degree to which objects are assumed into the body representation. When the objects were in full view of the observer, we found robust assimilation of the whole object, whereas the discontinuous object part was not assimilated. In the occluded condition, there was weaker assimilation for the whole object relative to when it was observed in full. The critical condition that emerged was that of the occluded discontinuous object parts, which were perceived as a whole. In this condition we found the discontinuous part of the object was assimilated, albeit more weakly than when the whole object was occluded. The results suggest that visual features interpreted as a whole object by the visual system, are more readily integrated as single structural unit into the body representation.

56.546 Analysis of similarity matrices and its application to the study of semantic and visual information processing in the inferior temporal cortex

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Representational similarity analysis has become a popular tool to study the nature of visual object representations (Kriegeskorte et al, 2008). Such analysis aims at characterizing patterns of brain activity via a so-called similarity matrix, which contains a similarity measure between all pairs of activity patterns elicited by a given stimulus set. This approach is particularly suited for comparing patterns of neural activity measured with different experimental techniques. Here we describe a computational approach based on distance-learning techniques and a statistical framework to uncover which stimulus dimensions are emphasized in the underlying representation. Our test is based on a restricted permutation test (Good, 2000) that we generalized to create a new "two-layer" test. The new test is specifically designed for hierarchically structured data such as natural object categories, to assess what level of a hierarchy a similarity matrix shares with the visual representation.

As a validation of the approach, we applied our method to the representational similarity analysis from Kriegeskorte et al (2008) based on patterns of fMRI activity response in human and monkey inferior temporal (IT) cortex to natural images of objects. We show that an image representation based on relatively low-level color and shape features is able to account for the underlying similarity matrix. These results cast doubts on the original interpretation of the data suggesting a high-level semantic visual representation at the level of IT. Using the proposed method we are able to relate different aspects of the similarity matrix to different types of low level features. Our findings suggest that careful consideration should be taken when conducting experiments with natural object categories.

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56.547 Holistic processing of words

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According to Farah's (1991) framework, recognition of different objects can be characterized by a continuum with faces at one extreme involving holistic processing, words at the other extreme involving part-based processing, and other objects somewhere in between. Face perception requires

fine, subordinate-level individuation of similar objects, and it is thought that holistic processing is developed as an optimal strategy to meet this recognition demand. More recent research has challenged the unique status of faces by showing that holistic processing is also developed for other homogeneous object categories after one has acquired expertise in individuating these objects. These findings suggest that holistic processing might be a more general hallmark of expertise, and raises the possibility that holistic vs. part-based processing may not be the critical dimension on which to differentiate processes involved in face, object, and word processing. We tested whether holistic processing would also occur for word perception, which has been shown to be a different type of perceptual expertise emphasizing basic-level categorization instead of fine individuation. We applied the often-used face composite task to English words and asked participants to match the target halves (left or right) of two 4-letter words while ignoring the irrelevant half. Clear evidence of holistic processing was found for words similar to that typically found for faces. In a second experiment, we found that holistic processing was larger for more frequently encountered stimuli (i.e., words compared with pseudowords), and larger for experts (i.e., native compared with second-language readers), indicating that holistic processing of words is sensitive to the amount of experience. Ongoing experiments are showing holistic processing for Chinese characters in experts. Overall, results cast doubt on the simple distinction between holistic face processing and part-based word recognition, and call for a richer cognitive model for explaining perceptual phenomena of different object categories.

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56.548 Spatial sampling may determine channel scaling in letter recognition

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Previous noise masking studies showed that only gratings or band-pass filtered letters exhibit perfect channel scaling (log-log slope=1.0 for channel frequency vs. stimulus peak frequency). Recognition of unfiltered letters requires frequency channels higher than the stimulus frequency, following a 2/3 slope. This deviation is explained by the increasing use of high frequency edges for recognition. Here we further investigated channel scaling in letter recognition using Sloan letters (stroke frequency (SF) =2.0 strokes/char) and simple and complex Chinese characters (CC1/CC6, SF=2.2/5.5 strokes/char, respectively). Band-pass noise masking was used to determine character recognition channels at different stimulus sizes. The channel frequency for Sloan/CC1 scaled along the 2/3 slope line, but for CC6 followed the 1.0 slope line despite of the sharp stimulus edges, indicating that Sloan and CC1 required a higher channel than did CC6 at the same stroke frequency. However, the more complex CC6 was much larger in size than Sloan/CC1 at the same stroke frequency. If the same channel with a fixed receptive field size inspects all these stimuli, and if it can collect enough samples over the larger CC6, the channel may be too coarse to collect enough samples over the much smaller Sloan/CC1. The deviation of Sloan/CC1 channels from perfect scaling thus may reflect the need to use smaller receptive fields (thus higher frequency channels) to obtain more spatial samples. To test this hypothesis, we measured the channel for CC6 recognition with randomly placed holes. The channel started to deviate from the 1.0 slope line with 35% hole coverage and approached the 2/3 line with 70% hole coverage while the stimuli were still recognizable. These results suggest that because channel frequency is related to the receptive field size in space, sufficient number of spatial samples collectable from an object may determine channel scaling.

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Attention: Divided

Tuesday, May 10, 3:00 - 7:00 pm

Vista Ballroom, Poster Boards 549 - 558

56.549 Divided attention impairs motion perception in older adults.

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Older adults' performance is known to be impaired when they perform secondary or interleaved tasks, compared to performing those tasks alone. It is not known, however, whether this impairment extends to simple low-level motion discriminations. We investigated whether performing a secondary task would affect motion coherence thresholds in both older and younger participants. Coherence thresholds (79% correct) were measured for judging the direction of translational global motion (3.4% contrast) in young (<25yrs) and elderly (> 65 yrs) participants. Simultaneous with the motion stimulus up to four, high contrast (34% contrast) squares flashed briefly either at fixation or peripherally at the edges of the motion stimulus. Participants either attempted to ignore these distracters or count them. Older adults' overall performance was similar to the younger adults. Thresholds were significantly higher when performed the counting task and under these conditions older adults were much more impaired than younger adults. Counting peripheral distracters was more detrimental to performance than counting at fixation but there was no correlation between motion coherence thresholds and counting task performance. Thus older adults are impaired when attention is divided and this extends to relatively low-level visual judgements. This pattern of findings is consistent with attentional modulation of global motion perception and models of age related cognitive decline.

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56.550 Pedestrians, Automobiles, and Cell Phones; Examining the Effects of Divided Attention and Aging in a Realistic Virtual Reality Street Crossing Task

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The ability to manage competing tasks has grown increasingly important as modern technologies, such as cell phones, have become pervasive. In two experiments, we characterized the dual-task costs associated with crossing a street while conversing on a cell phone, listening to music over headphones, or undistracted. The task was constructed in an immersive virtual reality CAVE with an integrated treadmill that allowed participants to traverse the simulated environment by walking. In Experiment 1, college-age adults performed crossings under very challenging crossing conditions. Participants were less likely to successfully complete a crossing when conversing on a cell phone (80% success rate) as compared to when listening to music (84%) or undistracted (84%). In Experiment 2, we examined age-related differences (adults age 65 and older compared to college age adults) in the same task, but under easier crossing conditions. Because gait control requires greater attentional control in older adults than in younger adults, we expected that dual-task street-crossing costs would be larger for older than for younger participants. The easier crossing conditions allowed younger adults to perform the task without dual-task costs (93% success rate overall), but older adults were less successful at crossing the street when conversing on a cell phone (81%) compared to when listening to music (87%) or undistracted (88%). Interestingly, whenever crossing performance was impaired, participants also spent a longer amount of time on the sidewalk preparing to initiate their crossing (~2s in both Experiments). We speculate that the dual-task costs associated with crossing a street under distraction are attributable, in part, to less efficient encoding of visual information and a diminished ability to recognize and act on safe crossing gaps. Additionally, older adults appear to be less flexible in dividing attention across competing tasks.

56.551 Does stress enhance or impair selective attention? The effects of stress and perceptual load on distractor interference

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The view that attention can be likened to a limited resource or capacity is generally accepted. One observation supporting this view is the finding that distractor interference obtained when the target appears alone under the low perceptual load condition is reduced when the target is embedded among nontarget items under the high perceptual load condition (Lavie, 1995). This implies that no spare resources were left for distractor processing under the high perceptual load. Similarly, in the context of stress research, acute stress is viewed as a resource-consuming situation by similar capacity approaches. The question is whether perceptual load and acute stress drain a common attentional resource. The present study examined this question by manipulating perceptual and stress loads. Participants conducted an Eriksen-type flanker interference task. Perceptual load could be low or high (2 or 5 neutral items, respectively). Participants in the stress group received a set of Trier Social Stress Test that generated speech anxiety and threatening self-esteem. The control group received a filler task. The stress induction was successful as indicated by the increase in the scores of the State-Trait Anxiety Inventory and the levels of salivary cortisol sampled before and after the stress induction. The effect of perceptual load interacted with the stress manipulation. Participants in the control group demonstrated substantial interference with low perceptual load, whereas such interference was eliminated with high perceptual load, replicating the previous studies. Importantly, the pattern of the results was opposite for the stress group. Participants showed virtually no interference with low perceptual load whereas a substantial interference occurred with high perceptual load. These results suggest that perceptual and stress load drains the same attentional resource for nontarget processing, resulting in an improvement of selective attention.

56.552 Evidence for the independence of pre-saccadic attentional shifts and voluntary attention

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We tested the allocation of attention in a task in which participants performed zero, one, or two saccadic eye movements, while voluntarily attending to a location in space. A discrimination target was presented at either the voluntarily attended location, at the saccade target, or at a movement-irrelevant location. Our results show that the perceptual performance at the different spatial locations was influenced by both, the direction of the saccade and the direction of the voluntary allocation of attention, and that these factors did not interact. In line with previous evidence, good performance was found if the discrimination target position coincided with the saccade target, as compared to movement-irrelevant locations, but voluntarily attending to the saccade target further added to this performance. While the findings illustrate that it is possible to allocate attention in a voluntary manner during the planning of saccades, they also argue for independence of the voluntary allocation of attention and the allocation of attention via saccades.

56.553 Psychoanatomy of visual attention: a unified account of quadrant and hemifield effects.

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The two hemispheres of the brain anatomically divide the right and left visual field along the vertical meridian (hemi-field representation). Cortical areas V2, V3, and V4 further subdivide the representation of the visual field along the horizontal meridian (quadrant representation). These anatomical divisions have been used in a number of studies as psychoanatomical landmarks to attribute functional processes to cortical visual areas. Hemifield effects have been shown in crowding and multiple object tracking (MOT) studies; and, quadrant effects have been observed in MOT and object priming studies. The psychoanatomical conclusion drawn from these studies is that visual processes that exhibit hemifield effects are mediated by areas with a hemifield representation, and those that exhibit quadrant effects are mediated by areas with a quadrant representation. In the present study, we tested a unified framework to account for these findings. Attention plays a critical role in performing all of the aforementioned tasks, and is

potentially a mediating factor. We propose that these findings can be attributed a scaling spotlight of visual attention that selectively enhances cortical activity in visual areas according to the scale/size of the selected target. Stimuli were constructed based on the average receptive field size of neurons in V1 (fine scale, hemifield representation) and V2-V4 (coarse scale, quadrant representation). The scaling hypothesis predicts that fine scale targets will exhibit hemifield effects, while coarse targets will show quadrant effects. The study examined two forms of the lateral inhibition (masking and crowding), which have been previously shown to exhibit hemifield effects using small stimuli targets. We replicated these findings and further showed that quadrant effects emerge with large coarse scale stimuli. The outcome of our experiments is concordant with the scaling hypothesis, and supports an attention account of hemifield and quadrant effects.

56.554 In Defense of Media Multitasking: No Increase in Task-Switch or Dual-Task Costs

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Extensive video game playing can increase one's attentional control and visual skills (Green & Bavelier, 2003). By contrast, Ophir, Nass, and Wagner (2009) suggest that heavy media multitaskers have decreased attentional control, particularly task switching ability. They suggest that this task switching deficit is surprising, considering that media multitaskers switch between tasks on a regular basis. However, it is possible that media multitaskers do not consistently switch between tasks, but rather, attempt to perform multiple tasks simultaneously. If so, they may show a deficit in task-switching performance because they must perform one, and only one, of two presented tasks. To investigate this issue, we used the Media Multitasking Index Questionnaire (Ophir, Nass, Wagner, 2009) to identify heavy and light media multitaskers and then tested both their task-switching and dual-task performance. Participants performed a number-letter task (Rogers & Monsell, 1995), in which they were to classify a number as odd or even and a letter as a consonant or vowel. Each participant completed both a task-switch and dual-task paradigm. The task-switch paradigm required switching between classifying the number or the letter across trials. The dual-task paradigm required the classification of both the number and the letter in each trial. In contrast to Ophir, Nass, and Wagner's (2009) findings, we found that heavy media multitaskers have a decreased switch cost compared to light media multitaskers, that is, they are able to switch between two tasks more efficiently. Furthermore, both groups showed comparable dual-task performance. These findings suggest that media multitasking does not interfere with attentional control and may even produce a better ability to switch between tasks.

56.555 Object identification has fixed capacity: Evidence for serial processing in the formation of perceptual objects

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Purpose: Many theories of vision include the formation of a structural description of perceptual objects as an intermediate step between feature extraction and semantic analysis. We ask whether the formation of perceptual objects is affected by divided attention. Can one create multiple perceptual objects independently and in parallel during early organization of the retinal image? Or, alternatively, must one apply a serial mechanism to create perceptual objects one by one? Previously, we found that categorization of animal images (e.g., wolf vs. bear) is limited by a fixed-capacity mechanism. In that study, either a structural or a semantic analysis of objects might have imposed the bottleneck. Here, we used a physical identification task that emphasizes the structural analysis of objects and minimizes the semantic analysis.

Methods: To measure perceptual capacity, we used the extended simultaneous-sequential paradigm, which can distinguish between unlimited- and fixed-capacity processes (Scharff, Palmer & Moore, in press). Observers searched for a specific target object among physically similar distractors. Stimuli were photographs of objects taken from several possible viewpoints. Three sets of artificial objects were used: cut-foam solids, toy-block constructions, and crumpled papers. For example, some trials required searching for a particular crumpled paper among similar crumpled papers, all seen from varying viewpoints. Thus, observers searched for a specific object, not a category or an image.

Results: Our findings were consistent with a fixed-capacity model for the physical identification of multiple objects. These findings rule out an unlimited-capacity model. We argue that there is a fixed-capacity limit to the formation of structural descriptions of objects. This is consistent with a serial mechanism, or with a parallel mechanism that acquires information from multiple objects at a fixed rate.

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56.556 **The effects of dividing attention on target enhancement and distractor inhibition**

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Visual attention is less effective at enhancing signal in extrastriate cortex when it is directed to multiple items rather than a single item (McMains & Somers, 2005) and this limit is due in part to suppressive interactions in visual cortex (Scalf and Beck, 2010).

Attention also plays an important role in inhibiting extrastriate signal evoked by task-irrelevant distractor items (e.g. Pinsk et al., 2004). Consequently, the same extrastriate interactions that constrain the attentional enhancement of task-relevant material may also have consequences for the inhibition of task-irrelevant material. In the current experiment, we examine whether directing attention to multiple items rather than a single item alters the ability of attention to inhibit evoked extrastriate signal to task-irrelevant items. We also examine whether such an effect is dependent on the presence of suppressive interactions among attended items. Participants underwent high resolution (1.3 x 1.3 x 1.8 mm) EPI scanning. They viewed eight-element displays and covertly monitored these for a color/shape/texture conjunction. We manipulated the number of attended items by asking participants to alternate between attending to one or three locations. We manipulated the likelihood of suppressive interactions among attended items by shifting the location of the attended items from a midline position (at which items are projected to different hemispheres and thus are less likely to interact) to a position in the upper right visual field (at which items are projected to the same hemisphere and thus are subject to local suppressive interactions). Preliminary data from V2 indicate that both target enhancement and distractor inhibition are compromised when attention is directed towards multiple items, but only when those attended items are subject to local suppressive interactions.

56.557 **Consolidation and Maintenance Processes in Visual Working Memory Lack an Extra Capacity for a Peripheral Pop-out Whereas Recognition Does Not**

Hae-In Kang¹(hennnn@naver.com), Joo-Seok Hyun¹; ¹Department of Psychology, Chung-Ang University

The comparison between supra-threshold visual working memory (VWM) representations and sensory inputs was reported to be rapid and automatic (Hyun et al., 2009). In the present study, we examined if engaging attention to a central memory task can impair detection of a peripheral pop-out change during VWM consolidation, maintenance, and recognition. In Experiment 1, the central memory task was a change detection task where subjects remembered colors of four boxes (sample array) and were asked to report presence or absence of a color change when another set of boxes (test array) showed up. They were also asked to detect a pop-out color change among a set of colored boxes displayed at periphery while the central task was being performed. The pop-out change among the peripheral boxes was manipulated to occur immediately after the sample array of the central task disappeared or during the middle of blank duration, or at the same time as when the test array appeared. In Experiment 2, the central memory task was replaced with short-term recognition task of four numbers and subjects were asked to determine whether the test number was in the sample array while the peripheral task was kept the same as Experiment 1. Results of these experiments showed that detection of a peripheral change was impaired both when the change occurred immediately after the sample array offset, and when it occurred during the middle of blank interval. However, this impairment was not observed when the pop-out change occurred simultaneously as the test array appeared. The same pattern of results was observed in Experiment 2. The results indicate that consolidating and maintaining memory items in VWM are resource-demanding process and thus lacking extra capacity for automatic detection of a peripheral pop-out whereas the recognition of memory items is relatively free of capacity-limitation.

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56.558 **Seated, standing, and stepping: Is the size of the useful field of view constant?**

James Reed-Jones¹(jjones04@uoguelph.ca), Rebecca Reed-Jones², Mark Hollands³; ¹Psychology, College of Social and Applied Human Sciences, University of Guelph, ²Kinesiology, College of Health Sciences, University of Texas at El Paso, ³School of Sport and Exercise Sciences, University of Birmingham

Useful Field of View (UFOV) is defined as the visual area from which information can be extracted at a brief glance. UFOV has been shown to correlate with vehicular crash risk, obstacle collisions, and propensity for falls. UFOV is normally tested while seated. This research examined the effects of both a change in posture and locomotion on UFOV performance. Ten participants were tested on a modified UFOV selective attention task while seated, standing, and stepping in place. The test consisted of a 67 ms simultaneous presentation of a letter (E, F, H or L) in the center of the screen and a black dot located at 57 degrees of eccentricity in one of eight possible locations encircling the central target (23 black rings were presented as distracters). This was followed by a 1 s masking field. The participants were then prompted for the letter identity and dot location. Participants were instructed to maintain central fixation throughout. Across all conditions participants had no difference in central target accuracy. However, a main effect of condition on peripheral target accuracy was found ($p = .037$). The mean accuracy reduced from 80.5% (standing) to 74% (seated) to 56.3% (stepping). Our findings show that a dynamic posture can affect UFOV selective attention performance in the periphery. Central processing was stable across all conditions, indicating that the decrease in peripheral accuracy while stepping was not due to inappropriate eye movements away from fixation. It does however indicate that whilst stepping, the size of the useful field of view significantly decreases, which affects peripheral performance. This finding has important implications for how the results of a UFOV test are used to evaluate the general size of the UFOV during varying activities, as the traditional seated test procedure may overestimate the size of the UFOV during locomotion.

Temporal processing

Wednesday, May 11, 8:00 - 9:45 am

Talk Session, Royal Palm 1-3

Moderator: Derek Arnold

61.11, 8:00 am

VEP study of receptive field sizes and feedback in human cortex

Yury Petrov¹(y.petrov@neu.edu), Jeff Nador¹, Jiehui Qian¹; ¹Psychology Department, Northeastern University

It has been known from animal neurophysiology that (i) receptive field sizes increase, and (ii) effects of stimulus contrast decrease (response saturation) along the visual pathway. The purpose of our study was two-fold. First, we wanted to confirm these properties of visual neurons for human brain. Second, we exploited these properties to reveal signatures of feedback interactions among visual areas. High-density VEPs evoked by a 16 deg diameter checkerboard contrast reversing at 0.5 Hz were collected from 22 normal subjects using 128-channel EGI Inc. system. In a given trial the stimulus appeared either as the full-field checkerboard (FF) or as a one-quadrant checkerboard (Q1, Q2, Q3, Q4). We then compared the sum of the 4 quadrants VEPs with the full-field VEPs: $D = Q1 + Q2 + Q3 + Q4 - FF$. The tested hypothesis was that the visual areas further down the visual processing stream with larger receptive fields and stronger response saturation will show larger differences D. Individual VEPs were averaged across epochs, interpolated and averaged across subjects, and then the VEP sources were localized on the average (FreeSurfer) cortex. We quantified the effect of the stimulus configuration with the area summation index $ASI = D / (Q1 + Q2 + Q3 + Q4 + FF)$. Distinct bilateral loci of surprisingly high ASI were found in the occipital (V1/V2/V3), temporoparietal junction (MT/LOC), temporal pole, and frontal pole areas. ASI increased from the occipital to temporal and frontal areas; the strongest ASIs were observed for temporal and frontal poles. These results indicate, that receptive field sizes increase along the visual processing stream. ASI also grew along the course of the VEP epoch in the occipital and temporoparietal areas. We suggest, that this increase indicates feedback from downstream visual areas of high ASI.

61.12, 8:15 am

Time to contact does not pop out

Eli Brenner¹(e.brenner@fbw.vu.nl), Alex Holcombe²; ¹Faculty of Human Movement Sciences, VU University Amsterdam, ²School of Psychology, University of Sydney

In visual search, items differing markedly from the others in a basic visual feature are quickly localized, irrespective of the number of distracters. Is time to contact such a basic visual feature? This question cannot be answered with conventional search tasks because time to contact necessarily changes continuously. We therefore developed two alternative tasks in which items converged towards a single point. In the first, before reaching the point, all items disappeared simultaneously. Participants indicated which they thought would have reached the point first. The items were assigned random speeds, with initial distance set so all except the target would have reached the point at the same time. The number of items strongly influenced the difference in time to contact required for the target to be picked reliably. Performance was only slightly better than if participants had simply picked the item that was nearest to the point when the items disappeared. On half the trials of the second experiment one item had a shorter time to contact than the others and on the other half all items had the same time to contact. Participants indicated as quickly as possible whether all items would arrive at the same time. Reaction time hardly depended on the number of items, but on average participants did not respond until the target's time to contact was less than half that of the other items. For trials with no target, they usually did not respond until when a target would have arrived. The results were similar for simulated motion towards the participant. When the speed heterogeneity was eliminated to make proximity a reliable cue, search was much faster. Apparently having a shorter time to contact does not make an item easy to detect. How then do we cross a busy intersection or negotiate a busy plaza?

Acknowledgement: Partly funded by an Australian Research Council Future Fellowship and Discovery Project to AH

61.13, 8:30 am

How well can we discriminate between stimulus onsets and offsets?

Christopher R.L. Cantor^{1,2}(dalek@berkeley.edu), Clifton M. Schor^{1,2}; ¹Vision Science Program, University of California at Berkeley, ²School of Optometry, University of California at Berkeley

It is well established that our visual systems are sensitive to the sudden appearance or disappearance of a visual object, and that we can judge the temporal order of such visual events with millisecond precision. Much of the literature on this topic has focused on whether stimulus onsets or offsets are processed faster, or whether the onset or offset of neural firing offers a more reliable substrate upon which to build representations of transient visual events. We asked whether observers could distinguish a pair of temporal envelopes applied to a simple visual object. Each pair contained onsets and offsets such that that average energy of the stimulus remained the same, but their temporal structure was exactly opposite (e.g. a disc briefly appearing with a temporal pattern that flashed ON-OFF-ON or OFF-ON-OFF). At long durations, the transient structure of this stimulus is obvious, but as the duration decreases below ~130 ms observers lose their ability to distinguish the temporal structure (direction) of the transient modulation, without ever losing the ability to detect the modulation itself (the phenomenon is not contrast dependent). We believe that the early visual system may combine timing signals originating in the ON and OFF channels, sacrificing the ability to discriminate between different kinds of visual events in order to produce reliable estimates of when they occurred.

61.14, 8:45 am

Introspecting on the timing of one's actions in a visuo-motor synchronization task

Andrei Gorea¹(andrei.gorea@parisdescartes.fr), Delphine Rider¹; ¹Lab Psychologie de la Perception, Univ Paris Descartes & CNRS

It is frequently claimed that the intention to perform an action is post-dictively 'constructed' by its perpetrator to match the action's outcome. Accordingly, the experience of volition presumably arises at the cost of causality. We test negatively one instance of such causality violation while showing that subjects fail to discriminate between their reactive and delayed motor responses. Subjects had to (1) synchronize a key-press with the end of a synchronization interval (SI) randomly chosen to be shorter or longer than their reaction time (RT) and (2) judge thereafter whether (Q1) SI had been sufficiently long to allow synchronization (requiring introspection of their mean RT), (Q2) their motor response had been 'reactive' (i.e. close to their RT) or delayed (requiring introspection on their RT and on their actual motor response time), or (Q3) whether SI was short or long (with respect to its implicit mean over trials; an 'objective' judgment). SI was identified by the filling-up time (0 to 500ms) of an annular 'gauge'. Subjects' best 'synchronization' motor response should be reactive for SIRT. Instead, the distributions of the motor response times were bimodal for the shortest (0ms) and longest (500ms) SIs and widely spread for intermediate SIs. Similarly to their responses to the 'objective' question Q3, subjects' introspective responses to questions Q1,2 strongly correlated with SI itself ($r = .62-.76$) and barely with their actual response times ($r = .03-.42$). Hence subjects' introspective judgments Q1,2 were not 'corrupted' by the outcome of their actions speaking against a causality violation. Subjects' reliance on the actual SI when deciding whether their action had been reactive or delayed (Q2) implies that they do not have retrospective access to (or do not remember) their motor decisions which amounts to say that they cannot decide on the intentionality of their actions.

Acknowledgement: ANR-06-NEURO-042-01

61.15, 9:00 am

A high temporal resolution and long-range mechanism that identifies which motion directions occur at the same time.Kazushi Maruya¹(kazushi.maruya@gmail.com), Alex Holcombe², Shin'ya Nishida¹; ¹NTT Communication Science Labs, NTT, Japan, ²School of Psychology, University of Sydney, Australia

Synchrony provides critical information for perceiving spatiotemporal structures from parallel inputs. Temporal resolution of binding by synchrony can be assessed by eliciting judgments of which features occur at the same time across two changing stimuli in separate locations. Temporal resolution is higher within a single sensory attribute than between two attributes (Holcombe & Cavanagh, 2001; Fujisaki & Nishida, 2010). It remains obscure whether characteristics of within-attribute binding are similar for various attributes. Here we show motion binding is distinct from others. Our stimulus consisted of two elements, each an oscillating 1/f-noise carrier windowed by a stationary Gaussian. We measured the threshold oscillation rate beyond which the observer could not tell whether the oscillations of the elements were in a specific relative phase (e.g., up at the same time as up, alternating with down-down) or in the opposite phase (up-down alternating with down-up). **RESULTS.** (i) High temporal resolution: Thresholds for motion were ~15Hz, significantly better than luminance or orientation binding measured at the same eccentricities. (ii) Remote interaction: Threshold rates remained high even at the longest inter-element separation tested (40 dva), while luminance and orientation thresholds dropped significantly. (iii) Path dependency: Threshold rates for motion remained high for various combinations of oscillation axes. However, an exception occurred when the oscillation axes formed a virtual T-junction, e.g., one element oscillated horizontally (0 deg), and the other vertically (90 deg), with the two aligned horizontally or vertically. Yet even with the same 90-deg difference, the combination of +45 deg and -45 deg, arranged in a virtual L-junction, showed a high threshold rate. Motion processing apparently has a special long-range mechanism, possibly to sense temporal relationships among potentially connectable local motion signals. This overturns previous suppositions (Holcombe, 2009; Nishida & Johnston, 2010) of how the architecture of the visual system limits temporal resolution.

61.16, 9:15 am

The weight of time: implied gravitational force enhances discrimination of visual motion durationAlessandro Moscatelli¹(a.moscatelli@hsantalucia.it), Francesco Lacquaniti²; ¹Laboratory of Neuromotor Physiology, Santa Lucia Foundation, Rome, Italy, ²Laboratory of Neuromotor Physiology, Santa Lucia Foundation, Rome, Italy

By means of five different experiments, we studied the anisotropies in the perception of motion duration. In each experiment, a single small target accelerated over a fixed-length path in one of four different directions in a fronto-parallel plane. Observers were asked to report whether a given test duration was longer or shorter than the standard duration. In Experiments 1 and 2, the directions were downward, upward, rightward, or leftward. In Experiment 1, target motions were superimposed on a computer-graphics pictorial scene, whereas in Experiment 2 the same motions were superimposed on a quasi-uniform background. In Experiments 3 and 4, the target moved along oblique lines, rotated by 45° relative to the cardinal axes, on the non-pictorial background. Finally, in Experiment 5 we used the same pictorial background and target motions as in Experiment 1, but we tilted the monitor and the scene by 45° to assess the role of the scene reference frame. We found systematic anisotropies in the precision of the responses, the performance being better for downward motion than for upward motion in all experiments. In the absence of pictorial cues, the difference in precision between downward and upward motion was much greater when the motion direction was aligned with the physical vertical (Experiment 2) than when it was tilted by 45° (Experiments 3 and 4). In the presence of pictorial cues, instead, the down/up difference in precision was comparable when the down direction defined by pictorial cues was aligned with the physical vertical (Experiment 1) or when it was tilted by 45° (Experiment 5). Moreover, only with pictorial cues was the discrimination in the downward direction systematically superior to that in the orthogonal directions. We argue that implicit knowledge about the effects of ubiquitous gravity force is incorporated in the neural mechanisms computing elapsed time.

Acknowledgement: Italian Space Agency (CRUSOE grant)

61.17, 9:30 am

Recalibrating Time PerceptionDerek Arnold¹(darnold@psy.uq.edu.au), Kielan Yarrow², Szonya Durant³, Warrick Roseboom¹; ¹School of Psychology, The University of Queensland., ²Department of Psychology, City University London, ³Department of Psychology, Royal Holloway London

Our sense of timing is malleable. For instance, visual signals can seem synchronous with unusually early sounds after prolonged exposure to auditory signals that precede visual signals. This represents a recalibration of timing perception. Here we report a sequence of studies that illuminate this type of phenomena. First, we show that despite assertions to the contrary, recalibration of audio-visual timing perception is shaped by the spatial proximity of audio and visual inputs. Next, we show that our sense of timing for intra-modal signals is similarly pliant, by establishing that direction reversals can seem synchronous with unusually early or delayed colour changes after adaptation to colours that lead or lag direction reversals. Finally, we establish that these data are best described by a shift in one of two criteria used to differentiate simultaneous from asynchronous inputs, as opposed to a realignment of sensory signals (with the transfer of information concerning one input accelerated or delayed relative to another). Overall, our data are consistent with dynamic timing perception criteria, which can be used to resolve ambiguities that might arise due to systematic variations in the physical and neural transmissions of sensory signals.

Acknowledgement: Australian Research Council

Face perception: Parts and wholes

Wednesday, May 11, 8:00 - 9:45 am

Talk Session, Royal Palm 4-5

Moderator: Allison Sekuler

61.21, 8:00 am

Multiple indices of holistic processing are uncorrelated with each other and with face identificationYaroslav Konar¹(konary@mcmaster.ca), Patrick J. Bennett^{1,2}, Allison B. Sekuler^{1,2}; ¹Psychology, Neuroscience & Behaviour, McMaster University, ²Center for Vision Research, York University

What role does holistic processing play in face recognition? Konar et al. (Psych Sci 2010; VSS2010) showed that the standard composite-face-effect (CFE) was not correlated with face identification. Gauthier et al. (VSS2010) suggested, however, that face identification may be related to other measures of holistic processing. Here we examine this suggestion directly by determining the relationships among several commonly used measures of holistic processing and face recognition. Eighty participants completed 4 tasks: CFE, the whole-part-effect (WPE), the face-inversion-effect (FIE), and the Cambridge Face Memory Test (CFMT; Duchaine & Nakayama, 2006). Participants were tested on versions of the WPE task that used masked stimuli (no hair, ears, or necks) or with stimuli embedded in a generic face outline (including hair, ears, and neck). We found significant CFEs and FIEs. The WPE based on internal features of faces was not significant, whereas the WPE based on whole faces was, suggesting that the WPE may not be driven exclusively by internal (relevant) features. Analyses of correlations among purportedly holistic/configural indices revealed that none of the effects (CFE, WPE, or FIE) were related significantly with one another, with the CFMT, or with upright face identification accuracy. The CFMT and upright face identification were correlated. These results suggest that holistic processing is not a unified concept: different tasks reflect different aspects of processing, with some tasks influenced by irrelevant features outside the face. Finally, although there may be a role for holistic processing in face identification of some special populations (Konar VSS2009), none of these standard holistic measures predicts performance for typical young observers on face identification using standard perception- or memory-based tasks. These results challenge the notion that holistic processing is a unified concept and ubiquitous for face perception.

Acknowledgement: NSERC and the Canada Research Chair program

61.22, 8:15 am

Dissociation between general holistic processing and holistic face processing: evidence from three cases of acquired prosopagnosiaThomas Busigny^{1,2}(thomas.busigny@uclouvain.be), Jason Barton², Bruno Rossion¹; ¹University of Louvain, Belgium, ²University of British Columbia, Canada

Understanding the functional impairment in acquired prosopagnosia – a defect at face recognition following brain damage – may be important for understanding the neuro-functional basis of normal face processing. A long-standing view is that prosopagnosic patients have impaired holistic/configural processing (e.g., Levine & Calvanio, 1989), that is, an inability to integrate simultaneously different visual features into a coherent global representation. However, it is not clear whether this impairment in holistic processing is general or specific for faces, particularly because prosopagnosia can be embedded in general visual agnosia. Here we addressed this issue with three cases of acquired prosopagnosia, who do not complain of any object recognition difficulties: PS (Rossion et al., 2003), LR (Bukach et al., 2006) and GG (Busigny et al., 2010). These patients were tested with the Navon hierarchical letters, testing general holistic processing, and two tests measuring holistic face processing, the face inversion effect and the whole-part advantage. We show that the three patients present with an entirely normal response profile in the Navon task: they are as fast as controls and they have a normal global-to-local interference during identification of local letters. In contrast, the three patients do not present with the normal effects in the holistic face processing tasks: they have neither a face inversion effect, nor a whole-part advantage. Thus, all three patients appear to encode facial information feature-by-feature, independently of the other features embedded in the whole facial context. These observations indicate that general holistic processing as measured with global/local interference in the Navon paradigm is functionally distinct from the ability to perceive an individual face holistically. We conclude that brain damage in adulthood may lead to selective recognition impairment for faces, because this is the only category of visual items for which holistic processing at a fine-grained (individual) level is necessary.

Acknowledgement: Belgian National Fund for Scientific Research (FNRS)

61.23, 8:30 am

Face-semblance leads to faster visual search and breaking interocular suppressionHua Yang¹(hua.yang@dartmouth.edu), Jason Gors¹, Ming Meng¹; ¹Department of Psychological and Brain Sciences, Dartmouth College

Humans excel at rapid visual processing of faces, especially compared to most non-face stimuli that have been tested. Is this processing advantage categorically specific for faces, or is it driven by image-level face semblance? We addressed this question via two sets of experiments: 1) whether face-like non-face stimuli (i.e. false-alarms produced by facial recognition software) could be detected faster in a visual search task; 2) whether these same stimuli overcome interocular suppression faster than non-face stimuli. Moreover, we assessed whether inversion and contrast-negation interacted with the effect of face-semblance. The visual search experiments revealed that face-semblance, even among non-face stimuli, led to faster target detection, but not pop-out like which occurs for faces (cf. Hershler & Hochstein, 2005; VanRullen, 2006). Both inversion and contrast-negation interacted with the effect of face-semblance. Face-semblance also led to faster breaking from interocular suppression, suggesting that this effect does not rely upon visual awareness. Interestingly, contrast-negation had a minimal influence on the role of face-semblance during breaking interocular suppression, despite contrast-negation being known to impair facial recognition. By contrast, stimulus inversion flattened the effect of face-semblance on breaking interocular suppression. In a control condition, inverted faces broke through interocular suppression slower than upright faces, in accord with previous findings (Jiang, Costello, & He, 2007). In conclusion, we show that, with or without awareness, the processing speed of visual stimuli is modulated by image-level face semblance. Moreover, face-like non-face stimuli are processed faster than non-faces. Contrast-negation interacts with the effect of face-semblance in visual search, but not in breaking interocular suppression, suggesting that contrast-negation affects face processing only at the stage following interocular suppression. Inversion interacts with the effect of face-semblance in both visual search and breaking suppression, suggesting that inversion affects face processing at an earlier stage than interocular suppression.

61.24, 8:45 am

Fixating the Eyes is an Optimal Strategy Across Important Face (Related) TasksMatthew F Peterson¹(peterson@psych.ucsb.edu), Miguel P Eckstein¹; ¹Dept. of Psychology, University of California, Santa Barbara

Introduction: Numerous studies have shown that humans make the vast majority of their fixations around the eye region when looking at a face (e.g., Barton et al., 2006). We have previously shown that this region contains a rich amount of information for identification (Peterson & Eckstein, 2008). However, humans accomplish many tasks with faces. Here, we investigated performance as a function of fixation location across four common face tasks and asked whether a simple eye movement strategy approximates optimality. Methods: Stimuli consisted of grayscale faces embedded in white Gaussian noise. The Identification condition contained ten neutral faces. The Gender condition contained 80 faces (40 female). The Emotion condition contained 140 faces (20 each of the 7 basic emotions; 70 female). The Happy-Neutral condition contained 100 faces (50 happy, 50 neutral). In each of 1500 trials observers fixated one of five randomly sampled points along the vertical midline of the face. A face was shown for 200ms followed by a response screen. We derived an ideal observer fitted with a human-like foveated visual system. Model parameters were fit to human data from the Identification condition and used to simulate predicted performance for the remaining tasks. Results: Human performance showed a remarkably consistent pattern across tasks, with performance peaking for fixations around the eyes and remaining relatively unchanged towards the nose tip. Foveated ideal observer results also predicted a peak toward the eyes with a relatively unchanged performance profile toward the nose followed by a steep drop-off above the eyes and below the nose tip. Conclusion: Natural systems analysis (Geisler, 2009) reveals that the combination of the foveated nature of the human visual system and the structure of the human face leads to a simple strategy of fixating the eye region being a rational approach toward maximizing performance on many common face-related tasks.

Acknowledgement: NIHEY-015925

61.25, 9:00 am

Local Jekyll and global Hyde: The dual identity of face identificationSébastien Miellet¹(miellet@psy.gla.ac.uk), Roberto Caldara¹, Philippe G. Schyns¹; ¹Institute of Neuroscience and Psychology, University of Glasgow, UK

The cornerstone of the face processing research agenda is an understanding of the processes underlying the identification of faces. We examined whether local or global information subtends face identification. To this end, we introduced a new methodology (iHybrid, see supplementary Figure 1 for a sketch of the methodology) that combines two identities in an on-line, fixation-dependent paradigm, which simultaneously provides local, foveated information from one face (supplementary Figure 1, the left eye of Brad Pitt, across spatial frequencies) and global, complementary information from a second face (the complementary facial information from William Macy) and then update the display at the location of the next fixation (See example movie for an illustration of the dynamics of fixations over one trial; the dot represents the fixation location:

http://www.psy.gla.ac.uk/~roberto/iHybrid_example.mov). iHybrids revealed the existence of two distinct, equally frequent and equally effective information sampling strategies for face identification. The local strategy involves local fixations on the eyes and the mouth; the global strategy relies on central fixations of the face. All observers used both strategies, often to recover the very same identity in different trials of the same experiment. We provide an illustration of the local and global information use in supplementary Figure 2. We conclude that the face system flexibly uses local or global stimulus information to identify faces and examine the implications of our findings for face identification.

Acknowledgement: The Economic and Social Research Council and Medical Research Council (ESRC/RES-060-25-0010)

61.26, 9:15 am

Kin recognition based on viewing photographs of children's faces is not affected by facial inversionLaurence Maloney¹(lmal1@nyu.edu), Maria Dal Martello²; ¹Psychology & Neural Science, New York University, ²General Psychology, University of Padova

Background: Many facial tasks such as identity recognition and judgments of emotion are more difficult when faces are inverted. We report an objective task (judgment of kinship of pairs of children) where task performance does not deteriorate with inversion of stimuli. Methods: 30 pairs of color photographs, each photograph portraying a frontal view of a child's face with background removed. Half of the pairs were siblings, half unrelated. The children's ages spanned 14 years. The distribution of age differences for related and unrelated pairs was matched as were gender differences. A total of 118 adult observers judged each pair as siblings or not. We summarized performance in each condition by signal detection d' estimates. Conditions: Upright face (UF); face flipped around a horizontal axis (IF); 180° rotated face (RF). Different observers participated in each condition. Results: Performance in the UF condition ($d' = 1.058$), IF condition ($d' = 1.197$), and RF condition ($d' = 1.048$) were not significantly different ($p > 0.05$). Likelihood criterion (β) values of UF ($\beta = 0.967$), IF ($\beta = 1.054$), RF ($\beta = 1.033$) also did not differ significantly ($p > 0.05$). The β values of UF, IF and RF were not significantly different from 1 ($p > 0.05$): there was no significant bias in classifying children as related or unrelated. Conclusion: Allo-centric kin recognition is not disrupted by inversion of the facial stimuli: the judgment appears to rely on inversion invariant cues. We discuss this result in conjunction with previous work [1,2] concerning localization of kin recognition cues in the face. [1] Dal Martello, M. F. & Maloney, L. T. (2006). *J Vis*, 6, 1356-1366. [2] DeBruine, L.M., et al. (2009). *Vis Res*, 49, 38-43.

Acknowledgement: MUIR

61.27, 9:30 am

The Moving Window Technique: A window into age-related changes in children's attention to facial expressions of emotionElina Birmingham¹(elinab@hss.caltech.edu), Tamara Meixner², Daniel Smilek³, Grace Iarocci¹, Jim Tanaka²; ¹Simon Fraser University, ²University of Victoria, ³University of Waterloo

Developmental investigations of face perception are needed to gain insight into processing strategies associated with face expertise. Previous studies on eye tracking have shown where children look when exploring a face, yet eye position can be dissociated from the allocation of attention. We developed the Moving Window Technique (MWT) in which the observer explores a face using a mouse-controlled window. Thus, we extend previous work by providing a direct measure of the location of the observer's attention and reveal the attentional strategies children use to decode basic facial emotions. We investigated the exploration strategies of children in a cross-sectional design with four age groups: 5-6 year-olds ($n=20$), 7-8 year olds ($n=35$), 9-10-year olds ($n=30$) and 11-12 year-olds ($n=33$). Children explored a degraded face with a window of high-resolution information and were asked to identify which emotion (e.g., happy, disgust, fear or angry) the face expressed. We found an age-related increase in accuracy and decrease in response time (RT) with the facial expression of fear showing the largest improvement in RT. Furthermore, while all groups spent more time exploring the mouth than the eyes, we found an increase in exploration time on the eye region at approximately 11-12 years (see Figure 1), suggesting a link between when children selectively focus on the eyes of faces and when their emotion recognition improves. In summary, the MWT technique is a promising method for investigating age-related changes in attentional strategies employed for the recognition of facial expressions.

Acknowledgement: Natural Sciences and Engineering Research Council of Canada
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Object recognition and scene perception: Neural mechanisms

Wednesday, May 11, 10:45 - 12:30 pm

Talk Session, Royal Palm 1-3

Moderator: Li Fei-Fei

62.11, 10:45 am

Closely overlapping responses to tools and hands in the left lateral occipitotemporal cortex.Stefania Bracci^{1,2}(stefanie.bracci@gmail.com), Cristiana Cavina-Pratesi³, Magdalena Letswaart², Alfonso Caramazza^{1,4}, Marius V Peelen^{1,4}; ¹Center for Mind/Brain Sciences, University of Trento, Italy, ²School of Psychology and Sciences Northumbria University, Newcastle upon Tyne, UK, ³School of Psychology, Durham University, UK, ⁴Department of Psychology, Harvard University, USA

Tools and hands are functionally related through their common role in action. In two fMRI studies we show that this functional relationship is reflected in the spatial distribution of hand- and tool-selective responses in the higher-level visual cortex. Results from Study 1 ($N=15$) showed that the processing of tools and hands (relative to mammals and scenes) recruited overlapping regions in left lateral occipitotemporal cortex (LOTc). This overlap was unlikely to be related to shared implied motion or general object processing properties, since motion-selective regions (hMT) and object-selective regions (LO) were located posterior to the tool-hand cluster, and did not respond selectively to either hands or tools. Study 2 ($N=15$) investigated whether the tool-hand overlap in left LOTc is specific to hands or generalizes to other body parts. Individual-subject region-of-interest analysis showed that tool-selective responses were more closely overlapping with hand-selective responses (80% overlap) than they were with non-hand body-part selective responses (38% overlap). Moreover, multi-voxel pattern analysis in left LOTc indicated a surprising degree of similarity between multi-voxel response patterns to tools and hands, but not between tools and other body parts. Together, these results indicate that tools and hands are represented in closely overlapping left occipitotemporal regions, despite differences in visual appearance and animacy. We propose that the functional organization of higher-level visual cortex is partly determined by the type of information that objects provide and specific network connectivity constraints: form-related object representations have to interact with those brain regions that specify the functional role of the objects (e.g. the left-lateralized fronto-parietal action network).

62.12, 11:00 am

STMVPA: Spatiotemporal multivariate pattern analysis permits fine-grained visual categorizationSergey V. Fogelson¹(sergey.fogelson@gmail.com), Peter J. Kohler¹, Michael Hanke¹, Yaroslav O. Halchenko¹, James V. Haxby¹, Richard H. Granger¹, Peter U. Tse¹; ¹Department of Psychological and Brain Sciences, Dartmouth College

Multi-voxel pattern analyses of neuroimaging data are traditionally performed on individual, temporally distinct observations (i.e. single brain volume acquisitions). However, as we have previously shown, the temporal dynamics of multi-voxel pattern classification of basic visual categories (faces and houses) vary systematically as a function of the visual area studied (Kohler et al., VSS 2010). We performed fast acquisition sequence fMRI experiments with slow event-related designs, using faces and houses as stimuli, and explored the spatiotemporal activity patterns within functionally defined regions of interest (ROIs) in occipital and ventral temporal cortex. We probed the temporal variability of the multi-voxel patterns by training and testing a classifier on multiple temporally contiguous acquisitions per observation, effectively "spatializing" time. This spatiotemporal multi-voxel pattern analysis (STMVPA) revealed higher classification accuracies within our ROIs as compared with single timepoint, spatial multi-voxel pattern analysis. In order to investigate patterns of activation outside our ROIs, we also performed a whole-volume analysis using a spatiotemporal searchlight. This analysis revealed regions not found using a standard, purely spatial searchlight (Kriegeskorte et al., 2006). Furthermore, STMVPA and the spatiotemporal searchlight allowed us to probe within-category distinctions, including the representation of gender and the identity of a face, that have thus far mostly resisted inquiry (except see Kriegeskorte et al., 2007). Our results suggest that reliable, temporally variable information is found within the hemodynamic response, and that this information can

be usefully exploited using STMVPA. We propose this temporal extension to multi-voxel pattern analyses as a methodological advance that increases the sensitivity and scope of traditional multi-voxel analyses of neuroimaging data, at least in cases where the temporal sampling of the hemodynamic response is relatively fine.

62.13, 11:15 am

Feedback of visual object information to cortex representing the “preferred retinal locus”, not the fovea, in individuals with macular degeneration

Daniel D. Dilks¹(dilks@mit.edu), Joshua B. Julian¹, Nancy Kanwisher¹; ¹McGovern Institute for Brain Research, MIT

A recent study (Williams et al., 2008) reported the surprising finding that the region of cortex representing the fovea contains information about objects presented in a peripheral retinal location, far from the fovea. Although other cases of feedback to retinotopic cortex have been reported before, this case is unusual in that the feedback apparently constructs a totally new representation in a different cortical region from the feedforward representation. Why is this new feedback representation constructed in foveal cortex? One possibility is that foveal cortex is engaged because it is a unique piece of neural hardware ideally suited for fine-grained visual computations (Mumford, 1991). Here we tested this hypothesis in individuals with macular degeneration (MD) who have lost all foveal vision, and who use a “preferred retinal locus” (PRL), a spared part of the peripheral retina, for face recognition, reading, etc. – essentially the functional equivalent of a fovea. If feedback information arises in foveal cortex because of its unique physical/computational properties, we predict the peripheral object information will be found in the foveal cortex in MD individuals, even though they have lost all foveal vision. By contrast, if feedback information arises in foveal cortex for some other reason (e.g., this is the location where most detail visual processing goes on in this person), then we predict the peripheral object information will be found in the region of cortex corresponding to the PRL, not the fovea, in MD individuals. Using fMRI, we found that the region of cortex representing the PRL, not the fovea, contained information about objects presented in another peripheral location. This result indicates that feedback is sent to foveal cortex in normally-sighted subjects not because of any unique physical characteristic of foveal cortex per se, but because this region of cortex is used most intensively for detailed visual processing.

Acknowledgement: This work was supported by NIH grant EY13455 to N.K.

62.14, 11:30 am

Translation Invariance of Natural Scene Categories

Marijn Catalin Iordan¹(mci@stanford.edu), Christopher Baldassano¹, Dirk B. Walther², Diane M. Beck^{3,4}, Li Fei-Fei¹; ¹Computer Science Department, Stanford University, ²Psychology Department, Ohio State University, ³Psychology Department, University of Illinois at Urbana-Champaign, ⁴Beckman Institute, University of Illinois at Urbana-Champaign

Natural scene categorization is fast, effortless, and invariant to many factors such as point of view, scale, and position in the visual field. Previous work has shown that scene category can be decoded from fMRI voxel activations in areas as early as V1, but more robustly in higher areas in the ventral visual stream, such as PPA, LOC, and RSC (Walther et al., 2009). A natural and fundamental question arises about this process: Where along the stream does the scene representation become invariant to geometric transformations? We address this question for the specific case of translation of natural scene images within the visual field. We conducted an fMRI experiment in which subjects passively viewed images of natural scenes presented either to their left or right visual fields (‘Left’ and ‘Right’ conditions, respectively). Using the voxel activations obtained during the experiment, we trained SVM classifiers to predict the category of the natural scene viewed by the subject. The training and testing sets each belonged to one of the two conditions above, for a total of four classification conditions (train on ‘Left’ and test on ‘Left’, train on ‘Left’ and test on ‘Right’, etc.). In retinotopic areas (V1 through V4) it was significantly easier to classify images when training and testing on scenes presented to the same part of the visual field, as opposed to opposite sides of the visual field. In PPA, however, we showed comparable classification accuracies whether we trained and tested on images from the same visual field or trained and tested on images from the opposite visual fields (translation invariance). This distinction suggests

that, just as LOC encodes geometrically invariant object representations, higher areas in the ventral stream (specifically PPA) abstract away geometric variance in encoding natural scenes.

Acknowledgement: Stanford SGF (MCI) NSF GRFP (CB) NIH R01 EY019429 (DBW & DMB & LF-F)

62.15, 11:45 am

Early vs. late components of category selectivity in the parahippocampal place area: A rapid acquisition fMRI study

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Complex patterns of category selectivity have been demonstrated in several visually-responsive cortical regions. For example, the parahippocampal place area (PPA) responds more strongly to scenes than to other visual stimuli, and it also shows preferences among non-scene stimuli, responding more to buildings than to other objects. We hypothesized that these different aspects of category selectivity might be attributable to early (feedforward) vs. late (recurrent) processing, and thus might impact PPA response at different points in time. To test this, we scanned subjects using a rapid acquisition fMRI protocol (TR = 250 ms) while they viewed four types of images (duration 500 ms; ISI 3 s) in a 2 x 2 design. Images had a large central foreground item that was either a building or a non-building object; independently, these objects were either presented on a scenic background or in isolation with no background. To compute the influence of scenic components, we subtracted responses to stimuli without backgrounds from those with scenic backgrounds. To compute the influences of foreground item category, we subtracted responses to non-building object stimuli from responses to building stimuli. Response differences related to foreground item category (building vs. non-building) were significantly delayed (~800 ms) compared to response differences related to the presence or absence of scenic backgrounds. We hypothesize that the delayed enhancement of activity for buildings relative to non-building objects may reflect feedback from other cortical regions that identify foreground object category; in this case, enhancing PPA response when the foreground object has navigational relevance. In contrast, scene vs. non-scene discrimination may occur more quickly because it operates on feed-forward calculations intrinsic to the PPA.

62.16, 12:00 pm

Neural coding of the size of space and the amount of clutter in a scene

Soojin Park¹(sjpark31@mit.edu), Talia Konkle¹, Aude Oliva¹; ¹Department of Brain & Cognitive Sciences, MIT

Estimating the size of a space and the level of clutter within it is central to our interactions and navigation through the world, for example, deciding whether or not to take a crowded elevator. The size of a space is a property defined by scene boundaries, while clutter is a property defined by the amount of objects within these boundaries. Given that these dimensions can reflect independent properties of indoor scenes, we examined whether size and clutter are differentially represented in any scene-selective neural regions.

We gathered images from 36 different indoor scene categories that spanned six levels of size (from a closet to an enclosed arena) and six levels of clutter (from empty to full), resulting in a fully crossed stimulus set. Observers were shown blocks of these scene categories and performed a one-back repetition task while undergoing whole brain imaging in a 3T fMRI scanner. Given this parametric design, we used a linear regression model on the multivoxel pattern activity from scene-selective regions. The regression model was trained with five categories per level and tested with the remaining categories, thus requiring generalization across different semantic categories to correctly predict the level of size or clutter. We found a significant interaction across region (RSC, PPA, LOC) and scene property (Size or Clutter; $F(2,10)=5.0$, $p<.05$): Patterns of activity in the parahippocampal place area (PPA) and the lateral occipital complex (LOC) parametrically predict both size and clutter, but patterns in the retrosplenial complex (RSC) predict only the size of the depicted space.

The results suggest that in the retrosplenial cortex, the size of the scene is coded independently of the amount of clutter within that scene, consistent with previous results showing complementary and distributed neural representations of properties describing the spatial boundary and the content of a scene.

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62.17, 12:15 pm

Contextual location information relevant to visual search in natural scenes is encoded in extrastriate visual cortex and the anterior intraparietal sulcus

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Humans are highly adept at detecting objects within natural scenes taking advantage of contextual cues to increase detection and recognition performance (Oliva & Torralba 2007). We show that both retinotopically defined dorsal areas (V3d, V3A, V3B) and ventral functionally defined areas (LO, PPA) contain information able to accurately discriminate the location contextually relevant to a cued target object. Eleven observers viewed a series of natural images and determined whether a cued object was present whilst whole brain fMRI data was recorded. Trial durations were 4.86 seconds with an initial 400 ms presentation of the cue word followed by a 250 ms ISI and stimulus presentation of 250 ms. Stimuli consisted of natural scenes (640 images, 17.5° square) with targets present in 50% of the images. Critically, target absent images were selected so that a single expected location (left/right lateralized) was contextually consistent with the cued target word. Experimental runs consisted of 16 presentations of each condition with observers completing 10 runs. We used multivariate pattern analysis to assess the accuracy of discriminating the location contextually relevant to the cue word. Only object absent scenes were used to isolate effects of context from that of the target objects. Accuracy for all regions-of-interest was greater than chance for identifying the location (left vs. right) contextually relevant to the cue. Accuracies were highest in dorsal areas V3d, V3B and the anterior intraparietal sulcus. In contrast, discrimination accuracy for the location (left vs. right) which contained the most salient object within the scene (determined independently [n = 100]) showed that only higher visual areas displayed significantly greater accuracy for context relative to saliency. Our results suggest that perceptual decisions utilizing contextual information for target location involve interactions between dorsal and ventrolateral visual areas containing task-relevant information and mediating parietal cortical areas governing attention.

Acknowledgement: Army grant W911NF-09-D-0001

Visual search

Wednesday, May 11, 10:45 - 12:30 pm

Talk Session, Royal Palm 4-5

Moderator: Yaffa Yeshurun

62.21, 10:45 am

Searching for many things at the same time: Saved by a log

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Suppose you are searching satellite images of North Korea for launch sites, steel plants, bridges, etc. More mundanely, suppose you are searching for anyone you know at a party. How does search proceed when you are looking for any one of many possible targets held in memory? In work in the 60s-70s, observers typically searched through 1-4 visible letters for any of 1-4 remembered letters. Effects of visual and memory set size were each linear and inefficient so the combination of visual and memory search was inefficient X inefficient. But, surely, your search for any friend in a crowd does not involve a serial search through the visible faces convolved with serial search through the set of all friends held in memory. Something must change when the number of items in the relevant memory set substantially exceeds working memory capacity. In our experiment, ten observers memorized sets of 1-16 photorealistic objects. They then performed 300 searches for any of those objects in visual displays with set sizes 2-16. One target was always present. Observers identified targets with mouseclicks. The effects of visual set size were linear for all memory set sizes. The effects of memory set size, however, are decidedly non-linear. RT increases with the log of memory set. Four visual set sizes X five memory sets yield 20 RTs. These 20 are a linear function of visual set size X log₂(memorySet)+1) The average

slope of this function is 23.5 msec. Average r-sq:0.94 (no log, r-sq=0.77). If logarithmic search through large memory sets generalizes, these values would allow you to find one of 1000 friends in a crowd of 100 in about 30 seconds (ignoring such issues as eye movements and navigating the party). By contrast, linear searches through memory with the same 23msec/step slope would take about 40 minutes.

Acknowledgement: ONR N000141010278

62.22, 11:00 am

Neural correlates of central versus peripheral target detection during complex visual search

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Extensive research has examined behavioural and brain responses during visual search when participants are required to indicate the presence or absence of a pre-defined target. According to Carrasco, Evert, Chang, and Katz (1995) detection of targets in search tasks becomes increasingly less efficient as the target is presented at more distant field eccentricities, reflected in increased reaction times (RTs). To date, however, the neural mechanisms underlying visual search for targets presented in different spatial locations are quite unclear. In the current experiment, adult participants performed a conjunction search task, searching for a red "X" in a field of green "X" and red "T" distractors, while event-related potentials (ERPs) were recorded. Behavioural results revealed significantly higher RTs when either 5 or 15 letters were presented and the target was in the periphery (>10 deg visual angle) compared to when it was in the centre (<10 deg visual angle; p<0.001). ERP results revealed larger amplitude activity for central versus peripheral targets in a positive-going component recorded from electrodes over the parietal cortex between 400 and 500 ms (p=0.002). This parietal activity was also larger for targets detected in a field of 5 versus 15 items (p=0.004). For the 5 item condition only, the earlier N2pc component recorded from electrodes over the occipital cortex also differentiated detected targets identified in the central versus peripheral visual field (interaction p=0.002). These data reveal differences in neural mechanisms underlying central versus peripheral target detection. Centrally presented targets elicit more parietal cortex activity than peripherally presented targets between 400 and 500 ms, perhaps reflecting increased focus of attention on the target item. For the 5 item condition, this focus of attention appears to be initiated by a bottom-up perceptual process originating in the occipital cortex. Data will also be presented from children aged 6- to 12-years.

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62.23, 11:15 am

Modeling Combined Proximity-Similarity Effects in Visual Search

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The goal of this study is to develop a computational model of visual search that takes into account various effects of grouping. To that end, we present two models that predict the effects of elements similarity (e.g., distractor homogeneity, target-distractor similarity) on visual search, and a third, extended model that can also account for the effect of spatial proximity. The first model provides a measure of search difficulty, while the second model is an algorithmic search mechanism. Both are based on the distribution of the pair-wise feature differences between display elements. In a first set of experiments (involving orientation and color search) distractor homogeneity and target-distractor similarity were systematically manipulated. In these experiments the spatial locations of the elements were random. The comparison of these models' predictions to those of several prominent models of visual search revealed that our models' predictions were the closest to human performance. In our third, extended model the pair-wise feature differences are replaced by a distance measure that is a superposition of feature-wise difference and spatial distance: $d = aD_f + (1-a)D_s$, where D_f is the feature difference and D_s is the spatial distance, after normalization. This change enables the model to predict, for instance, that visual search is easier when stimuli with similar features are also spatially clustered than when the same stimuli are randomly located. In our second set of experiments we systematically manipulated both elements' feature similarity and spatial proximity. The findings suggest that the extended model can adequately predict human performance using the same 'a' value for all participants. This 'a' value ($a \approx 0.4$) suggests that the spatial distance between

elements has a slightly stronger effect on search performance than that of the feature differences. This is consistent with previous findings regarding the combined effects of proximity and similarity on perceptual grouping.

62.24, 11:30 am

Does crowding obscure the presence of attentional guidance in contextual cueing?

Steven Fiske¹(sfiske@mail.usf.edu), Thomas Sanocki¹; ¹Psychology, University of South Florida

The contextual cueing effect was initially thought to be the product of memory for the repeated context guiding attention to the target location. Recent work has disputed this explanation pointing to the absence of decreased search slopes (derived from response time x set size function) in contextual cueing, a criterion used for establishing the presence of attentional guidance. However, we argue that the candidate source of guidance in contextual cueing – memory for the repeated displays – is fundamentally different from previously established ‘guiding attributes’ which are derived from features of the display items themselves. It is this difference, rather than a lack of attentional guidance, that explains the failure to observe decreased search slopes in contextual cueing. While increasing the number of items in the display will necessarily increase the amount of guiding information in typical feature-based guidance, the resulting changes in the perceptual characteristics of the display may attenuate memory-based attentional guidance. In particular, visual crowding may impair peripheral recognition of the target at larger set sizes due to the increased density of items in the local target region. This could reduce the efficacy of the guidance as set size increases thereby yielding steep search slopes. We investigated the influence of crowding on contextual cueing by varying the density of items in the local target region. When crowding was eliminated, we observed results characteristic of attentional guidance – a significant reduction in search slopes between the novel and repeated conditions. No contextual cueing effect was observed when crowding of the local target region was enhanced. These findings indicate that the absence of decreased search slopes in contextual cueing is the product of increased crowding at larger set sizes rendering the memory-based attentional guidance less useful.

62.25, 11:45 am

Measuring the handoff of the attentional template from working memory to long-term memory

Nancy Carlisle¹(nancy.carlisle@vanderbilt.edu), Geoffrey Woodman¹; ¹Psychological Sciences, Vanderbilt University

Theories of visual attention propose that target template representations in working memory implement top-down control over the selection of information in complex scenes during visual search. However, theories of learning and automaticity propose that as we gain proficiency at performing a task, processing shifts between relying on working memory representations to a reliance upon long-term memory. Together these theories suggest that as we repeatedly search cluttered visual scenes for the same target, the attentional template that guides selection should be transferred from working memory to long-term memory. In this study, we tested this prediction using event-related potentials (ERPs) to directly measure what is maintained in working memory during visual search. Our analyses focused on the contralateral-delay activity (or CDA), which is a lateralized ERP component that measures the online maintenance of information in visual working memory (Vogel & Machizawa, 2004). Participants performed a visual search task for an item matching a lateralized target cue. The identity of the target cue remained the same across runs of consecutive trials before a new target object was cued. Measuring the amplitude of the CDA elicited by the cue allowed us to determine how the involvement of working memory changed with experience searching for the same target. We found that the large amplitude CDA measured during the initial searches following a target identity change rapidly diminished and was essentially gone within 10 trials. Our findings show that the target representations that control visual attention are rapidly handed off to long-term memory from working memory.

62.26, 12:00 pm

Search and Destroy: A new approach to understanding inhibition in visual search

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Observers can use explicit foreknowledge of a feature of an upcoming target to guide search. However, little is known about observers’ use of explicit foreknowledge that a specific feature will not match the upcoming target. In a series of experiments, we presented observers with either “ignore” cues (cf. Munneke et al., 2008) that validly indicated the color of a nontarget item (rather than the color of the target item) in the upcoming display, or “neutral” cues. Surprisingly, observers were unable to use “ignore” cues to speed search; instead, knowing the color of a nontarget item on the upcoming display slowed search. This cost for “ignore” cues compared to neutral cues was consistent across several experiments using several different types of “ignore” cues. We conclude that observers are unable to explicitly avoid selecting items appearing in to-be-ignored colors. Instead, we propose observers use a strategy of immediately selecting the irrelevant item in order to subsequently inhibit it, a strategy we term “Search and Destroy”. In a follow-up experiment, we used a probe dot detection paradigm (cf. Kim & Cave, 1999) to determine whether observers were initially selecting the to-be-ignored item as predicted by the “Search and Destroy” hypothesis. Results confirmed this prediction; when probes were presented early in the search process, observers responded more quickly to probes appearing at the location of the to-be-ignored item compared to probes appearing at the remaining locations (453 ms vs. 485 ms, $p < .05$). This suggests that observers were selecting the to-be-ignored item prior to inhibiting it. We suggest that “Search and Destroy” may be a useful framework for interpreting other instances of inhibition in search shown in the previous literature, and that “Search and Destroy” may be an adaptive strategy under special conditions, such as when there are abundant items matching the to-be-ignored feature.

62.27, 12:15 pm

Does repeated search in scenes need memory? When contextual guidance fails, memory takes over.

Melissa Vo¹(mlvo@search.bwh.harvard.edu), Jeremy Wolfe¹; ¹Harvard Medical School, BWH

Imagine searching a new kitchen for spoons. Before you find them, your eyes dwell briefly on eggs. We would assume that looking AT eggs would tend to improve subsequent search FOR eggs. However, our experiments show that this intuition is oftentimes wrong. We recorded eye movements while observers searched the same, continuously visible scene for 15 different objects. Over approximately 30 seconds of search, search performance did not improve despite increasing scene familiarity: Finding the 15th object was no faster than finding the 1st. Incidental fixation on one object (e.g., eggs) while searching for another (e.g., spoons) did not benefit subsequent search for eggs. Moreover, a 30 second preview of the scene did not improve subsequent object search. Observers searched the scene as if they had never seen the scene before. Interestingly, when asked to search for the same object in a 2nd block, after hundreds of intervening searches in other scenes, the second search was 100s of ms faster. Memory for targets can guide search.

Hollingworth (2006) has shown that observers develop memory for more than just search targets when viewing a scene. Why didn’t observers use memory during our initial object searches? We hypothesize that “contextual guidance” (knowledge that in kitchens pots are often located on stoves) was fast and strong enough to render memory guidance useless. If that is so, memory might guide if context is weakened. Observers performed 15 successive searches in artificial indoor scenes that were contextually coherent (pot on stove) or incoherent (pot on floor) locations. Across 15 searches within a scene, RT decreased by 700 ms when context was incoherent but only 250 ms in coherent scenes. In contextually incoherent scenes, incidental object fixations predicted subsequent RT for those objects. These findings show that in incoherent scenes, when context fails, memory guides search.

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Wednesday Morning Posters

Motion: Higher-order, objects, and illusions

Wednesday, May 11, 8:15 am - 12:15 pm
Royal Palm 6-8, Poster Boards 301 - 317

63.301 The nature and the role of colour information in motion processing

Mark Edwards¹(Mark.Edwards@anu.edu.au), Alexander Coningham¹, Rebecca Rae-Hodgson¹; ¹Department of Psychology, Australian National University

Two specific questions relating to colour and motion processing were addressed: 1) whether colour information is carried by a system that is sensitive to both colour and luminance information, i.e. a double-duty system, and/or a system that is sensitive purely to colour information; and 2) whether colour can be used as a segmentation cue in the pooling of motion signals. The nature of the colour input was determined by using a global dot-motion stimulus (for which performance cannot be mediated by attention-based tracking) in which the signal dots changed their luminance polarity as they moved, but maintained their colour information. The effect of luminance contrast, speed and eccentricity were investigated. A purely colour-sensitive system would be able to use the consistent colour signal, regardless of the contrast of the inconsistent luminance-signal. It was found that observers could extract motion only at both low luminance-contrast and low speeds ($<12\sigma/s$). No evidence for a purely colour system was obtained, even at very low speeds and for foveally presented stimuli. The extent to which colour can be used as a segmentation cue was assessed by determining whether noise dots of one colour and luminance combination affected the extraction of a global-motion signal from noise dots of a different colour and luminance combination. It was found that colour could not be used as a segmentation cue for standard global-motion processing (consistent with earlier results), however it could be when a stimulus was used that tapped the form-specific global-motion system (VisRes, 2010, 429-438). These findings indicate: a double-duty motion system exists, both in the fovea and parafoveal region; this system is only sensitive to low speeds; a purely colour-sensitive system does not exist, and colour cannot be used as a segmentation cue in standard motion-pooling but it can in form-specific processing.

63.302 Asymmetric Effects of Spatial Suppression on First- and Second-Order Motion

Davis M. Glasser^{1,2}(dglasser@cvs.rochester.edu), Duje Tadin^{1,2}; ¹Center for Visual Science, University of Rochester, ²Brain and Cognitive Sciences, University of Rochester

Increasing the size of a high-contrast moving grating makes its motion more difficult to discriminate (Tadin et al., 2003). This counterintuitive effect, termed spatial suppression, is believed to reflect antagonistic center-surround mechanisms. It is unknown, however, whether spatial suppression differentially affects first-order and second-order motion processing. Converging evidence from psychophysics and neuroimaging suggests that while first- and second-order motion signals are usually strongly correlated in natural stimuli, they are processed by separate mechanisms. Thus, we hypothesized that spatial suppression may not equally impact the perception of different orders of motion signals. Here, we investigated the effect of stimulus size on first- and second-order motion perception using compound grating stimuli (Nishida & Sato, 1995). The stimuli were high-contrast $2f+3f$ gratings, which contain first- and second-order motion information moving in opposite directions. Varying the stimulus onset asynchrony (SOA) between frames changes which signal dominates perception. Motion is perceived in the first-order direction for shorter SOAs and in the second-order direction for longer SOAs. We found that this established relationship changes when the stimulus size is varied. Specifically, increasing stimulus size decreases the influence of first-order motion information, even at low SOAs that normally favor first-order direction. This result suggests that spatial suppression has a considerably stronger effect on first- than second-order motion perception.

Acknowledgement: NEI R01 EY019295

63.303 Detection of object motion during self-motion: psychophysics and neuronal substrate

Finnegan Calabro¹(fcalabro@bu.edu), Lucia-Maria Vaina^{1,2}; ¹Department of Biomedical Engineering, Boston University, ²Department of Neurology and Radiology, Harvard Medical School

The extraction of object motion from a visual scene is critical for planning direct interactions with one's surroundings, and is of particular interest and difficulty when the observer is moving. To investigate the visual processes underlying object motion detection during self-motion, we presented observers ($n=23$) with a stimulus containing nine objects, eight of which moved consistent with forward observer translation, and one of which (the target) had independent motion within the scene. Results showed that observers' abilities to detect the target depended significantly on the speed of the object within the scene (Exp 1), but that performance was independent of observer speed, and therefore retinal velocity (Exp 2, $n=7$). Results were compared to predicted performances for target selection based on relative differences in speed and direction among the objects, and were not consistent with either strategy. Instead, these data suggest that observer performance used a flow parsing mechanism in which self-motion is estimated and subtracted from the flow field. In an event-related fMRI paradigm using the task from Exp 1, we found a distributed pattern of activations of occipito-temporal, posterior parietal and parieto-frontal areas. Granger causality analysis among these activated regions revealed two major highly connected networks. One network involved a set of interconnected early, bilateral, visually responsive areas (including KO, hMT+ and VIPS). We posit that these regions underlie the perception and formation of a visual representation of the stimulus. The second network was comprised of primarily higher-level, left hemisphere areas (including DIPSM, FEF, subcentral sulcus and postcentral gyrus) that have been reported to be involved in the use of sensory inputs for preparing motor commands. We suggest that these networks provide a link between the perceptual representation of the visual stimulus and its interpretation for action.

Acknowledgement: NIH grant R01 NS064100 to LMV

63.304 Deficit Of Temporal Dynamics Of Detection Of A Moving Object During Egomotion In A Stroke Patient: A Psychophysical And Meg Study

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To investigate the temporal dynamics underlying object motion detection during egomotion, we used psychophysics and MEG with a motion discrimination task. The display contained nine spheres moving for 1 second, eight moved consistent with forward observer translation, and one (the target) with independent motion within the scene (approaching or receding). Observers' task was to detect the target. Seven healthy subjects (7HS) and patient PF with an infarct involving the left occipital-temporal cortex participated in both the psychophysical and MEG study. Psychophysical results showed that PF was severely impaired on this task. He was also impaired on the discrimination of radial motion (with even poorer performance on contraction) and 2D direction as well as on detecting motion discontinuity. We used anatomically constrained MEG and dynamic Granger causality to investigate the direction and dynamics of connectivity between the functional areas involved in the object-motion task and compared the results of 7HS and PF. The dynamics of the causal connections among the motion responsive cortical areas (MT, STS, IPS) during the first 200ms of the stimulus was similar in all subjects. However, in the later part of the stimulus (>200 ms) PF did not show significant causal connections among these areas. Also the 7HS had a strong, probably attention modulatory connection, between MPFC and MT, which was completely absent in PF. In PF and the 7HS, analysis of onset latencies revealed two stages of activations: early after motion onset (200-400 ms) bilateral activations in MT, IPS, and STS, followed (>500 ms) by activity in the postcentral sulcus and middle prefrontal cortex (MPFC). We suggest that the interaction of these early and

late onset areas is critical to object motion detection during self-motion, and disrupted connections among late onset areas may have contributed to the perceptual deficits of patient PF.

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63.305 Extrastriate cortical activity reflects segmentation of motion into independent sources

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Identical local motion signals can arise from an infinite number of object motions in the world. Here we address the question of how the visual system constructs percepts of moving objects in the face of this fundamental ambiguity. In order to do this, the visual system must somehow integrate motion signals arising from different locations along an object's contour. Difficulties arise, however, because contours present in the visual scene can derive from multiple objects and from occlusion. Thus, correctly integrating respective objects' motion signals presupposes the specification of what counts as an object. Depending on how this form analysis problem is solved, dramatically different object motion percepts can be constructed from the same set of local motion signals. In the present study, we applied fMRI to investigate the mechanisms underlying the segmentation and integration of motion signals that are critical to motion perception in general. Methods: In a block design fMRI experiment we held the number of image objects constant, but varied whether these objects were perceived to move independently or not. Results: BOLD signal in V3v, V4v, V3A, V3B and MT varies with the perceived number of distinct sources of motion information present in the visual scene. Conclusion: These data support the hypothesis that these areas integrate form and motion information in order to segment motion into independent sources (i.e. objects) thereby overcoming ambiguities that arise at the earliest stages of motion processing.

63.306 Perception of Motion in Natural Scenes

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Human motion sensitivity is typically measured using artificial displays such as random dot kinematograms that provide close control over stimulus parameters but poorly approximate natural input. We developed a technique that allows measurements of sensitivity to motion components using movies of natural scenes. Using a 2-AFC match-to-sample paradigm, we investigated the tolerance of the visual system to speed noise for movie stimuli. Individual frames of grayscale 1-second movies of natural scenes were analyzed using derivative-of-Gaussian filters that defined local orientation, contrast and spatial frequency, and were then reconstructed using a subset of these filters. On each successive frame elements were tracked locally based on distance and similarity, creating a measure of cumulative displacement through time. Speed noise could then be added by altering the displacement of each element. A noiseless source movie was presented for 1 second, followed by a reference movie that contained a fixed amount of speed noise and a target movie containing an additional amount of speed noise under control of a staircase procedure. There were six levels of speed noise from 2.5% increase to 80% increase in logarithmic steps. Subjects were asked to identify which of the simultaneously presented movies were more similar to the source movie. A bootstrapping procedure identified the threshold for 75% correct identification. Subjects showed a monotonic increase in thresholds with the addition of pedestal noise that was significantly fit by an equivalent noise function ($t=13.44$, $p<.001$). Previously we reported finding a dipper function in a similar pedestal paradigm using an orientation discrimination task with static images and suggested that this function arises from dependence upon a higher-level perceptual template that defines the location of expected features. The present results suggest a difference in the encoding of static orientation and speed information for moving and static natural scenes.

63.307 Bistable Apparent Motion Axis Determined by Axis of Surrounding Object

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Dynamic dot quartets undergoing apparent motion appear to move along either of two orthogonal axes with perception switching unpredictably between the two interpretations. The axis of motion (horizontal or vertical) can be biased by embedding a quartet in a larger framework that is undergoing apparent motion. We were interested in whether a static spatial context could bias the perceived axis of motion. In the first experiment a real bar ran along the medial axis of the quartet either horizontally or vertically, and in the second experiment a virtual or Kanizsa bar was employed. In both cases the quartet's motion axis was biased parallel to the bar. In the third experiment the quartet was centered within a real or virtual object (ellipse, rectangle, diamond: each with 2:1 aspect ratio) such that one axis of the quartet lay along the principal medial axis of the object and the other perpendicular to it. Viewers were biased to see quartet motion along the axis of the surrounding object for both real and virtual objects. A fourth experiment found the same result with disks placed in dipole, rectangle or diamond configurations but lacking well-defined real or virtual bounding contours. This implies that perceptual grouping of the disks into geometric objects permits definition of an axis sufficient for inducing quartet alignment. In the first two experiments there was a real or virtual medial contour dividing the quartet, while in the latter two experiments there was no perceived contour, only the abstract medial axis of the object, suggesting that the medial axis representation (Blum, 1973) may have some real foundation in perception. Induction of apparent motion parallel to an object's principal axis may be less surprising if the "motion" is more properly understood as an object undergoing a transformation about an axis.

63.308 Making predictions from kinematics and causal intuitions: a dissociation between judged causality and imagined locations

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To mentally extrapolate the trajectory of moving objects disappearing from sight, different sources of information can be exploited. Among them, the memory of its last visible position and movement, its inferred movement through time, and the general understanding of the causal relations between objects in the scene are particularly important. It is often assumed that these cues are integrated into unified analog mental representations. To investigate the mental representation of imagined movements and their relation with our intuitions about the nature of the physical events, we used a novel experimental paradigm in which a causal attribution task was combined with a motion prediction task. Participants were instructed to imagine the trajectory of a moving object disappearing behind a screen and to estimate the degree to which the movement was launched by another moving object. To test the impact of causality, we modified a launching event by introducing either a temporal delay or a spatial interval between the movements. Compared to a situation in which the target object remained visible through its entire trajectory, participants were unable to precisely predict the actual position of the target when it was occluded. Furthermore, their predictions were misaligned with their judgment of causality: participants predicted the actual position of invisible moving objects better for events that they judged less causally correct than for events they judged more causally correct. To see if some other high-level physical representations could affect the prediction, we tilted the slope of the track such that the balls would either roll downward or upward, resulting in no obvious difference from the horizontal track condition. Overall, our data suggest that kinematics and cognitive parameters of imagined dynamical events do not merge into a unitary mental model simulating actual states of the world.

63.309 Representation of stimulus identity in apparent motion

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When a static stimulus appears at two different locations successively with some time interval in between, we perceive its motion across the two locations – the illusion of apparent motion. Previous research shows that when a target stimulus is presented on the apparent motion path such that it matches spatio-temporally with the presumed movement of the appar-

ent motion representation, the target is easier to detect (Schwiedrzik et al., 2007). This and similar studies (Yantis and Nakama, 1998, Muckli et al., 2005) suggest that there is some representation maintained across the apparent motion path. However, it is unclear whether this representation contains stimulus specific information such as stimulus identity.

We examined this question using a target discrimination paradigm. After presenting 4-5 cycles of apparent motion across two left or two right-tilted gratings, a target (also a left or right-tilted grating) was briefly presented at the midpoint of the motion path. Subjects reported whether the orientation of the target grating matched that of the motion-inducing stimuli or not. This was contrasted with target discrimination in a flicker condition where the two gratings at different locations were flashed simultaneously instead of successively, abolishing the percept of apparent motion.

The results show that subjects are more likely to respond that the target matches the inducing stimuli for the apparent motion condition, compared to the flicker condition. Furthermore, this is accompanied by decreased target discriminability in the apparent motion condition. This increased response toward target-stimulus matching in the apparent motion condition suggests that stimulus identity is maintained in the apparent motion representation.

63.310 Apparent phi-motion in sequences of Eisenstein's October

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Perceiving dynamic scenes requires perceptual, attentional, and cognitive processes that generate the impression of real-world motion. Motion can be perceived if two objects are shown at different positions in the visual field. While this is called beta movement the phi-phenomenon represents a special case where the viewer sees 'objectless motion' (Wertheimer, 1912). Recent attempts in research has focused on gaining insight into the viewer's mind but filmmakers need to anticipate the manipulation of the viewer's perception and attention during the process of making the film. The present research was inspired by the work of the Russian filmmaker, Sergei Eisenstein (1898-1948), who is credited with inventing the film montage, or sequencing of specifically timed edits for emotional impact. One of the earliest examples for this technique is his silent film *October: Ten days that shook the world* (1927). Here we analyzed the famous machine gunner sequence from this movie where the viewer perceives the illusion of shooting. To examine if this illusion could be based on apparent phi-motion individual shots were shown as still images while participants had to indicate the most informative region in each shot. The systematic distribution of the regions of highest information together with the presentation time of the shots support the idea that Eisenstein intentionally provoked the viewer's attentional focus back-and-forth shifts within the spatial frame of subsequent shots and at appropriate frequency to induce the impression of objectless motion.

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63.311 Shifting selection may control apparent motion

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When two stationary objects at different locations are presented alternately in succession, they can be perceived either as two stationary flickering objects, or as two objects switching back and forth between the two locations (apparent motion). Previous research suggested that attentive tracking is linked to the perception of apparent motion (Cavanagh 1992; Verstraten, Cavanagh, & Labianca, 2000; Verstraten and Ashida, 2005). According to a strong version of this account, the correspondence problem of what went where may be determined by the position of spatial selection over time. We tested this possibility by tracking the position of spatial selection using an electrophysiological correlate (Contralateral Delay Activity). Participants were presented with an ambiguous apparent motion display (6 frames, 1.5Hz) that could be perceived as either two objects (an "x" and

a "+") rotating or two objects switching from one location to the other. We found that when switching motion is perceived, attention was locked to one object and shifted back and forth as the selected object appeared alternately at the two locations. The results suggest an important role of the distribution of selective attention in organizing perceptual structure over space and time.

63.312 Representational Momentum Varies Across Objects

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When objects undergo smooth or implied motion and unexpectedly vanish, observers report their vanishing point as farther along the motion trajectory than the actual vanishing point. This forward displacement is known as representational momentum (RM; Freyd & Finke, 1984). Two studies investigated whether and how stimulus type influences RM. If RM is due to a memory error, then the magnitude of RM should be unaffected by stimulus type. If RM reflects motor simulation or prediction, then stimuli that afford perception-action coupling should produce different RM patterns. In Experiment 1, 60 observers performed the standard representational momentum task with an arm, wrench, and rectangle. Trials were blocked by stimulus type in a within subjects design. On each trial, the stimulus underwent implied rotation around a central axis. 60 participants judged whether a subsequently presented probe was identical to the final stimulus view. Results show that, collapsed across stimulus type, RM increased across blocks. Further, the arm provided for the smallest RM, the rectangle most, and the wrench in between. This suggests that human movements may be differently treated by the visual system. Experiment 2 replicated the previous study but used an arm and a tree (a non-manipulable object) and stimulus type varied across subjects. Results show an interaction between stimulus type and block. Forward displacements for the arm decreased from Block 1 to Block 2, while forward displacements for the tree increased from Block 1 to Block 2. The results of these studies indicate that representational momentum varies across stimulus type. Future studies will examine alternative explanations such as the complexity of the image, attentional factors, meaningful vs. meaningless movement, and animacy vs. inanimacy.

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63.313 A novel variant of the Ouchi-Spillmann illusion

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Op artist Hajime Ouchi's book on "Japanese Optical and Geometrical Art", first published in 1973, featured a striking motion illusion in which a black-and-white checkered disk appeared to float and shift against a checkered background (1). The illusion languished in obscurity until vision scientist Lothar Spillmann stumbled upon it and introduced it to the vision research community (2), where it has enjoyed enormous popularity. Here we report a novel variant of the Ouchi-Spillmann illusion. Whereas in the classical version the disk pattern has an opposite orientation to that of the background, the new illusion consists of a single checkered pattern with an overlaid solid ring (that is either black or white). The ring's position becomes unstable upon observation, shifting from side to side if the checkered pattern is horizontal (i.e. in its longest orientation axis), or moving up and down if the checkered pattern is vertical. The strength of the illusion is enhanced for patterns made with elongated checks, and diminished for patterns with more symmetrical (i.e. square) checks. As in the classical Ouchi-Spillmann's illusion, the observer's head and eyes movements appear to facilitate the perception of motion. We propose that the original Ouchi-Spillmann illusion and the novel variant reported here are modulated by the observer's exploratory and fixational eye movements, including both saccades and microsaccades. Further, the illusory motion in the new variant may result from eye position changes along the same axis as the perceived direction of motion. (1) Ouchi H (1977) Japanese Optical and Geometrical Art. Dover, New York. (2) Spillmann L, Heitger F, Schuller S (1986) Apparent displacement and phase unlocking in checker-board patterns. 9th European Conference on Visual Perception, Bad Nauheim.

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63.314 Perception of intentions and mental states in autonomous virtual agents

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Comprehension of goal-directed, intentional motion is an important but understudied visual function. To study it, we created a two-dimensional virtual environment populated by independently-programmed autonomous virtual agents. These agents (depicted as oriented triangles) navigate the environment, playing a game with a simple goal (collecting “food” and bringing it back to a cache location). The agents’ behavior is controlled by a small number of distinct states or subgoals—including exploring, gathering food, attacking, and fleeing—which can be thought of as “mental” states. Our subjects watched short vignettes of a small number of agents interacting. We studied their ability to detect and classify agents’ mental states on the basis of their motions and interactions. In one version of our experiment, the four mental states were explicitly explained, and subjects were asked to continually classify one target agent with respect to these states, via keypresses. At each point in time, we were able to compare subjects’ responses to the “ground truth” (the actual state of the target agent at that time). Although the internal state of the target agent is inherently hidden and can only be inferred, subjects reliably classified it: “ground truth” accuracy was 52%—more than twice chance performance. Interestingly, the percentage of time when subjects’ responses were in agreement with one another (63%) was higher than accuracy with respect to “ground truth.” In a second experiment, we allowed subjects to invent their own behavioral categories based on sample vignettes, without being told the nature (or even the number) of distinct states in the agents’ actual programming. Even under this condition, the number of perceived state transitions was strongly correlated with the number of actual transitions made by a target agent. Our methods facilitate a rigorous and more comprehensive study of the “psychophysics of intention.” For details and demos, see ruccs.rutgers.edu/~jacob/demos/imps.html

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63.315 Which kinds of motion silence awareness of visual change?

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Objects changing in hue, luminance, size or shape appear to stop changing when they move—this is silencing (“silent updating”, Suchow & Alvarez, VSS 2010). But there are many kinds of motion, and we sought to determine which of them cause silencing. Consider that when an object moves but the observer’s gaze does not, two types of motion occur simultaneously: the object moves in space, and its image moves on the retina. We created two complementary displays that dissociate these two kinds of motion. In the first, the changing objects remain stationary while the observer tracks a fixation mark that moves across the display; this produces motion on the retina, but not in space. In the second, the changing objects move across the display and the eyes follow; this produces motion in space, but not on the retina. Comparing silencing across the two conditions revealed that motion on the retina is responsible for the full effect of silencing, whereas motion in space is irrelevant. Next, we asked whether silencing is produced by the sensation of motion or by movement. To clarify this distinction, consider the motion aftereffect and the “motion without movement” illusion (Freeman, Adelson, & Heeger, 1991), both of which produce the appearance of motion even though the “moving” objects remain in fixed locations. Here, after prolonged exposure to a rotating pinwheel, observers viewed a display with stationary objects that changed in luminance, and they reported the apparent rate of change. We found that the motion aftereffect produces silencing, which shows that it is the sensation of motion, not movement, that causes silencing. Together, these results suggest that local motion signals interfere with processing of changes in hue, luminance, size, and shape; this interference likely comes in the form of suppression or misattribution of non-motion changes to motion.

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63.316 Asymmetric spatial distortions of moving objects

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Visual motion causes a number of illusions in which object positions are spatially mislocalized. Moving objects themselves are also subject to spatial distortions (e.g. Ehrenstein, 1925; Anstis et al., 1999; Zanker et al., 2001). In the present study we show that moving diamond shapes or isosceles triangles composed of dots at the vertices appeared asymmetrically distorted, with the leading dot seen extended in the direction of motion and the trailing dot compressed toward the center of the shape. These distortions are independent of contrast polarity and differential contrasts of dots composing the figure, and scale proportionally to the object’s speed. Explicitly manipulating attention to the leading or trailing part of the shape changed the spatial distortions. When participants were required to respond to the orientation of lines superimposed on the leading dot at random time points during the motion, while keeping steady fixation, they perceived the shapes more accurately. Attention to the trailing dot, however, increased the shape distortions. We discuss several possible explanations of these findings, including motion extrapolation specific to leading parts of an object, motion deblurring specific to trailing parts, and spatiotemporally specific attentional repulsion due to the locus of attentional tracking lagging behind the moving object.

63.317 Collisions are seen before they are heard

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Several studies have found that auditory information has an advantage over visual information in terms of neural processing time, leaving a binding problem when judging simultaneity of auditory and visual events. Therefore, when a moving object collides with another object, the percept of the sound of the collision may precede the visual event. In the current study, participants made a temporal order judgment between briefly presented sounds and visual moving objects colliding into, and disappearing behind, a centrally fixated target. The speed of the visual stimulus and the relative timing between the visual and auditory event were manipulated. We observed an illusion whereby a moving dot was perceived to collide with a fixated target prior to the onset of a physically synchronous beep. We found that this asynchrony increased with increasing dot speed. The processing advantage for the moving object was observed although there was no motion after the collision. This finding supports the idea that moving visual objects (and their collisions) have a perceptual advantage over auditory events.

Perceptual organization: Mechanisms and models

Wednesday, May 11, 8:15 am - 12:15 pm

Royal Palm 6-8, Poster Boards 318 - 329

63.318 Visual adaptation of causality

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Collision events, in which a moving object abruptly stops and an adjacent object immediately takes off in the same direction, cause a striking phenomenal experience of causality. To this day the jury is still out on whether this experience is the result of vision (achieved by perception) or cognition (achieved by reason). To address this, we used visual adaptation to reveal the contribution and undeniably visual properties of underlying neural populations coding for causality. Data from 12 subjects, recruited in two different laboratories, consistently showed that prolonged viewing of perceptual causal events results in a substantial negative aftereffect on the judgment of subsequent ambiguous events. These causality aftereffects are spatially specific, affecting only those locations that were adapted, and could not be explained by adaptation to other low-level features, like motion or contrast. Our results provide strong support for hard-wired

channels in retinotopic cortex that implement visual routines for the analysis of fairly complex, and seemingly high-level features of visual scenes: cause and effect in perceptual events.

63.319 Adaptive cue combination in a visual estimation task

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Introduction. Uncertainty is a curse, and one antidote is the active collection of additional information. Information, though, can be costly. We asked subjects to attempt to hit a small, invisible target on a touch screen. They earned points for each hit. The only cues to the target's location were dots drawn from a Gaussian distribution centered on the target. The dots appeared one by one as the subject repeatedly pressed a key, but each dot cost a small amount subtracted from the subject's potential reward. Would subjects know when to stop 'buying' information?

Methods. Eight subjects participated in each of two conditions (200 trials per subject; conditions interleaved in short blocks). (1) Target value started at 40 points and decreased by two points per cue purchased. (2) Target value started at 60 points and decreased by six points per cue purchased. The optimal rule maximizing expected gain was to purchase seven and four cues, respectively.

Results. (a) Subjects earned an average of 14.06 points per trial (SD=2.19), which is 76% of the optimal expected gain of 18.55 points per trial. (b) All subjects correctly purchased more cues in the 40 point condition (M=8.04, SD=1.5) than the 60 point condition (M=5.87, SD=0.72), $t(14)=3.68$, $p < .003$. (c) Statistical tests indicate that almost all subjects were risk averse in that they purchased more cues than dictated by the optimal rule. The exceptions were one subject who was risk seeking in the 40 point condition (M=5.38, SD=1.36), $t(99)=-11.9$, $p < .001$, and one other subject who was not significantly different from optimal in the 40 point condition (M=7.03, SD=1.55), $t(99)=0.19$, $p > .05$.

Conclusion. When balancing the costs and benefits of purchasing information to reduce visual uncertainty, subjects collected more information than predicted by the ideal observer.

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63.320 Leftward Prism Adaptation Increases Sensitivity to Local Cues in Healthy Individuals

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Adaptation to right-shifting prisms has been shown to diminish the symptoms of hemispatial neglect in patients with parietal lesions (Rossetti et al., 1998). In contrast, left-shifting adaptation in healthy individuals has been shown to simulate symptoms of neglect, such as a rightward bias in line bisection tasks (Colent et al., 2000) and a reduction in global interference in the perception of Navon figures (Bultitude & Wood, 2010). The current study tested whether leftward prism adaptation (PA) can also increase local processing biases in healthy individuals. In experiment 1, participants' susceptibility to the rod-and-frame illusion (RFI) was measured before and after prism adaptation. A significant increase in susceptibility to a small frame version of the RFI (thought to be driven primarily by local interactions between the rod and the contours of the frame) was found for leftward PA, whereas rightward PA caused no change in susceptibility. To confirm this effect, experiment 2 was conducted using a more pure measure of local processing: the simultaneous tilt illusion (STI). Again, it was found that illusion susceptibility increased post-adaptation for the left-shifting prism group only. Experiment 3 tested whether PA can also modulate global processing independent of local processing by having participants make a saccade to perceived vertical in the presence of a large tilted frame. A marginally significant result was found in that the leftward PA group was less susceptible to the tilted frame post-adaptation. Results from all 3 experiments suggest that leftward PA in healthy individuals can simulate the local processing bias of neglect patients primarily through increasing sensitivity to local visual cues, and that the attentional effects of PA not only modulate lateral shifts of attention, but also shifts from one level of processing to another.

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63.321 Perceptual Grouping Gives Rise to Object Perception: Evidence from Psychophysical Reverse Correlation

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When an object's component parts are not readily perceived as a linked whole due to occlusion, the visual system must perceptually group the disparate elements into a single coherent unit. Several principles of perceptual grouping, with varying influences on object formation, have been proposed and yet our understanding of the differences in the representation arising from different grouping cues remains rather poor. We adapted the psychophysical reverse correlation technique to measure the percept of two partially occluded objects formed by the grouping of common elements. Stimuli contained two perceptual rectangles to which we added orthogonal occluders, creating four discrete surface patches that could be grouped in two different ways. Manipulation of intrinsic parameters of each linking cue biased grouping in one direction. For example, during color similarity linking, two patches were light gray while the remaining two were dark gray, promoting the percept of two distinct gray rectangles. A second condition (blocked by session) was included for each linking cue in which the occluders were positioned "below" the rectangles (i.e., the rectangles were not occluded). These displays comprised the base images to which Gaussian distributed noise was added on each trial. Subjects determined the orientation of the perceived rectangles and classification images for each condition were created by aggregating noise images across trials. Results yielded access to an approximation of subjects' internal representation of the base images. Similar sectors of the display contained statistically significant pixels in both occluded and non-occluded conditions, suggesting that the underlying representations of the percepts were considerably congruous. Critically, in the occluded condition each subject showed diagnostic pixels located on occluded portions of the rectangles. However, since no information about the rectangles was actually present in these occluded regions, this provides evidence that perceptual grouping is used to demark surface patches into perceived objects.

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63.322 How much contrast information is needed for reliable fast image recognition ?

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The visual system faces the problem of extracting biologically-relevant information from a large flux of input data. This can be obtained by summarizing complex scenes to extract meaningful features (Barlow, 1959; Marr 1976) by using image primitives (edges, bars), encoded physiologically by specific configurations of receptive fields (Hubel & Wiesel, 1962). This work follows a pattern-filtering approach, based on the principle of efficient information coding under real-world limitations (Punzi & Del Viva VSS-2006). The model, applied to black and white images predicts from very general principles the structure of early visual filters and identifies salient features (edges, lines) providing highly compressed "primal sketches" of visual scenes (Del Viva & Punzi VSS-2008). Human subjects are able to identify such sketches (2AFC procedure) in rapid identification tasks (10-20 ms), with very high accuracy (up to 90%), comparable to that for fully detailed original images (Del Viva et al. VSS-2010). Here, we extended previous computational and psychophysical experiments to gray-level images to investigate whether this early visual image processing can make use of a larger amount of input information. Results with 4 gray level images (2 bits) provided sketches with a lesser or equal level of compression, and comparable information content to those obtained with 1 bit. Performance in recognizing image sketches did not improve by increasing input information either. Our results provide support to the idea that only a very limited contrast information is used for fast image recognition, and that this is fully explained by our model of efficient information within constraints.

63.323 Image recognition is based on efficiently coded features

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The visual system faces the problem of extracting biologically-relevant information from a large amount of input data. It has been proposed long ago that complex scenes are initially summarized by extracting only a small amount of meaningful features ("primal sketch") (Barlow, 1959; Marr 1976) The present study follows a pattern-filtering model, based on the principle of efficient information coding under real-world limitations (Punzi & Del Viva VSS-2006). The model predicts from very general principles the structure of efficient information-coding patterns, that provide highly compressed "sketches" of visual scenes (Del Viva & Punzi VSS-2008), containing only a limited number of salient features. The aim of this study is to directly test whether the "salient features" extracted by this computational model actually correspond to the visual features that human subjects use to discriminate between natural images. We performed a psychophysical experiment by briefly presenting (20 ms) hybrid images composed by mixing points sampled from the "salient features" (according to our algorithm) of one image, with points extracted from another (background) image using a different algorithm. The subject's task was then presented with the two original images and asked to judge which of the two more closely resembled the hybrid, using an AFC procedure. All subjects indicated with high probability (>80%) the image that had been sampled based on the salient features predicted by our algorithm as the better match. This performance remained unchanged when a random unrelated image was proposed as a possible match in place of the image actually used as background, showing that the background match events are mainly of random nature. These results support the reliability of our model in predicting the salient features that human subjects uniquely use to identify visual scenes under very fast viewing conditions.

63.324 A Universal Retinotopic Mapping of V1 with Respect to Anatomy

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Individual differences in the size and shape of area V1 require that retinotopic mapping (RM) be performed on subjects before proceeding to an experiment. Despite variations in volumetric localization, V1 can be accurately identified using cortical surface anatomy (OP Hinds, 2008. Neuroimage 39:1585-1599). Using surface anatomy as a normalization guide, we asked whether the specific pattern of RM within V1 can be predicted for any given subject by anatomical features alone. We performed retinotopic mapping with BOLD fMRI (6 scans, 120 TRs, TR=3s, 3mm voxels, at 3 Tesla) upon 10 subjects using both phase-encoded (PE) and multifocal (MF) methods (these data combined here). MPRAGE images (1mm isotropic voxels) for each subject were processed with FreeSurfer to identify and digitally inflate the cortical surface. The spherical cortical surface from each subject was then registered to an atlas and area V1 identified. The eccentricity and polar angle values were combined and then compared with data from each individual subject. Smooth, continuous retinotopic mappings within V1 were obtained such that all data points were resolved with standard deviations <2° of eccentricity and <30° of polar angle. Cross-validation of each individual subject to the template produced from the remaining 9 found a mean correlation of 0.48 +/- 0.07 for polar angle and 0.28 +/- 0.08 for eccentricity. The high agreement of the data between subjects as indicated by the small standard deviations demonstrates that reasonable estimates of V1 RM can be derived from anatomical features alone. Accurate prediction of the RM in V1, based purely on cortical surface anatomy, can greatly simplify studies of the visual cortex in healthy and patient populations. Future work will examine the reliability of retinotopic mapping from surface anatomy outside of area V1.

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63.325 Specific functional asymmetries of the human visual cortex revealed by functional Near-Infrared Spectroscopy.

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Over the past decades, the animal and human visual systems have been widely studied. Based on multiple invasive reports and neuroimaging studies, it is now well established that the cytoarchitecture of the visual cortex is related to its functional organization, which is the called retinotopic organization of the visual cortex. The present study aims to investigate retinotopic mapping as well as specific vertical and horizontal functional asymmetries within the human visual cortex using functional near-infrared spectroscopy (fNIRS). Black and white wedge checkerboard stimuli were randomly presented to the four visual fields (VF) quadrants of eight healthy adults in order to quantify and compare the localization and the amplitude of hemodynamic visual cortex responses to each stimulated VF quadrant. As expected, results showed a stronger visual cortical activation in the contralateral hemisphere and in the inverse upper/lower quadrant to the stimulation. We also measured significant stronger activations in the upper visual cortex when lower hemifield stimuli were presented compared to activations in the lower visual cortex when upper hemifield stimuli were showed. This confirms the vertical asymmetry of the visual cortex previously reported by neuroimaging and behavioural studies. The present work constitutes the first study showing functional asymmetries in the visual cortex using fNIRS and confirms the reliability of this non-invasive technique for functional mapping of the human brain.

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63.326 Multi-focal and phase-encoded retinotopy compared

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Phase encoded (PE) retinotopic mapping stimuli are traveling wedges and rings while multi-focal (MF) stimulation divides visual space into discrete regions driven by a set of pseudorandom sequences (S Vanni, 2005. Neuroimage 27:95-105). Simulations of the BOLD fMRI system predict that MF and PE approaches should have similar statistical power, and studies have shown comparable qualitative results in area V1. How MF mapping quantitatively compares to the PE approach, however, has not been examined empirically.

We performed retinotopic mapping (RM) with BOLD fMRI (6 scans, 120 TRs, TR=3, 3mm voxels, at 3 Tesla) upon 10 subjects using both PE and MF methods. Quadratic residue sequences defined stimulation (5Hz flicker) in 6 second intervals for the 48 MF sectors, and prohibited simultaneous activation of adjacent sectors. PE were coherent wedges and rings of sectors that traveled every 6 seconds. Eccentricity and polar angle values from each subject were combined within an anatomical V1 region defined by registration to a spherical atlas of cortical topology (Hinds et al 2008). We computed the correlations of each individual's map with a template derived from the data for the remaining nine subjects. We averaged these correlations as a measure of the reliability of each method.

12 minutes of PE scanning produced an average correlation for polar angle similar to 24 minutes of MF scanning (PE 0.51 ± 0.1sd vs MF 0.47 ± 0.14sd); 12 minutes of MF scanning produced significantly poorer results (0.26 ± 0.30sd), with discontinuities in the retinotopic map.

Despite having equivalent predicted statistical power, MF mapping was empirically half as powerful as PE approaches within area V1. Although adjacent sectors were never simultaneously illuminated, lateral inhibition may nonetheless contribute to this effect. More generally, MF presentations appear similar to visual noise and may be a suboptimal cortical stimulus.

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63.327 A time window for temporal facilitation

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Collinear facilitation is an enhancement in the visibility of a target by laterally placed collinear flankers (COL). A non-collinear configuration (parallel, side-by-side, SBS) produces less facilitation. In our previous study (Lev & Polat; When simultaneous presentation results in backward masking VSS 2010), we explored the facilitation using ERP recording and found that the latency of SBS is delayed by about 10 ms compared to COL. The results suggest that the temporal delay is underlying the reduced facilitation. Here we report results from a study (behaviour and ERP) in which we presented the flankers (in either COL or SBS configuration) at target-flankers separation of 3λ (duration=60 ms) either before the target (forward masking) (ISI= 20, 40, or 60 ms, SOA= 80, 100, or 120 ms) or simultaneously with the target (ISI=0). We found that presenting the flankers 20 ms before the target enhanced the response speed, resulting in a shorter latency of the P1 component about 10 ms for both COL and SBS, compared to the simultaneous presentation (ISI=0). This effect was not found for ISI of 40 and 60 ms. Behaviour data support the ERP results. The timing that we used doesn't suggest an attentional confound. Altogether, the results support the suggestion that the signal evoked by the flankers in both COL and SBS configurations is delayed due to slow lateral proration time. Thus, forward presentation of 20 ms enables a better temporal matching of lateral and target signals (temporal integration), boosting up lateral facilitation.

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63.328 Mechanism(s) for Apprehending Numerosity based on several Visual Properties

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Do visual numerosity judgments depend only on the perceptual strength of the difference between targets versus distractors? If so, then the visual property that makes targets different from distractors should not matter. Specifically, if the perceptual strength of the difference between targets of type T1 and distractors of type D1 is equal to the perceptual strength of the difference between targets of type T2 and distractors of type D2, then these two combinations of targets and distractors should support identical performance across various tasks requiring numerosity judgments. To address this question, we assessed the accuracy of four observers who each, in 12 separate runs, made judgments while the magnitude of the difference between targets and non-targets was varied. Each run involved a different one of the possible combinations of four numerosity discrimination tasks and three visual properties. All targets and distractors were equiluminant and brighter than the gray background. Target objects differed from non-targets in their size, orientation, or color along the L-M axis. Three of the numerosity discriminations used a field of 14 objects and required discriminating 0 versus 1 targets, 1 versus 2 targets, and 2 versus 6 targets. The fourth task required discriminating 5 versus 15 targets in a field of 35 objects. All four observers showed clear differences: these judgments depend on more than simply the perceptual strength of the difference between targets versus distractors. These results suggest that more than one mechanism is involved in numerosity judgments (e.g., parallel individuation and analog magnitude estimation) and that these processes have differential access to information conveyed by the three visual properties.

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63.329 The integration of color information in symmetry detection

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To perceive a symmetry pattern, the observer has to determine whether two parts of an image are mirrored copies of each other about a symmetry axis and then to integrate the image feature pairs about the same axis to form the percept of a symmetry pattern. We investigated the role of color in such integration process in symmetry detection with a noise masking paradigm. In each 2AFC trial, a symmetric target was randomly presented in one interval while a random dot control was presented in the other and a random dot noise mask was presented in both intervals. The task of the observer was to determine which interval contained the symmetric target. The target density threshold was measured with PSI staircase method at 75% correct response level. In Experiment 1, the target was either red or

blue while the masker was one of six possible chromaticity on the isoluminant plane. The symmetry detection threshold was greatest when the target and the mask were of the same color and decreased as the difference in chromaticity between the target and the mask increased. This suggests that the symmetry detectors are color-selective. In Experiment 2, both the target and the masker contained one, two or four colors. The axis orientation of the symmetric target was either 45° or 45° away from the vertical. The noise dot density ranged from 0 to 10%. The symmetry detection threshold increased with the noise densities. The symmetry detection thresholds decreased with the number of the colors in the stimuli at low and median noise densities but not at high densities. This result cannot be explained by independent color selective channels which would predict the threshold decreases with the number of colors. However, the result can be accounted for by a nonlinear integration across mechanisms.

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Visual memory: Capacity and resolution

Wednesday, May 11, 8:15 am - 12:15 pm

Orchid Ballroom, Poster Boards 401 - 422

63.401 The tradeoff between memory capacity and precision is weaker in recall than in discrimination

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The capacity of the visual working memory depends on the precision of the representations. Previously we have shown very limited working memory capacity for detecting changes in the shape (phase structure) of the radial frequency (RF) patterns. We tested whether the memory capacity is limited also when the shape is defined, not by the phase structure, but by the amplitude of RF patterns. Two different tasks were used for estimating the capacity: delayed discrimination and recall. The delayed discrimination thresholds were measured with 2-interval forced choice setup using Quest procedure. In the first interval, 1-6 stimulus items were presented with random amplitudes (.1-.5), RFs (3, 4 or 5), and phases (0-360 deg). In the second interval, after the 1.5 s blank period, the amplitude of one of the items was either increased or decreased. The observers' task was to say whether the changed item had higher amplitude in the first or in the second interval. In the recall experiment, the second interval consisted of a cue box and a probe item, and the observers' task was to adjust the amplitude of the probe to match the amplitude of the item in memory. Gaussian functions were fitted to the distribution of the adjustment errors. For one item, the amplitude thresholds were low (0.01-0.05) and the adjustments precise (standard deviations 0.01-0.03). As the number of items increased from 1 to 6, there was a linear, 6-14 -fold increase of the thresholds (0.14-0.29) but only 3-fold increase of the standard deviations (0.03-0.10). There were individual differences, but no sudden or complete breakdown in performance was observed for any subject. The results confirm the tradeoff between memory capacity and precision, and show that the amount of the tradeoff depends on the individual observers and the task by which the memory capacity is measured.

63.402 A Biased-Competition Account of Visual Working Memory Performance

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One of the most successful models of how visual information is processed by the human brain is the biased-competition model of attention (Desimone & Duncan, 1995) which posits that multiple objects within a receptive field compete for representation, and that attention serves to bias neural responses towards some objects over others. To date, few studies have investigated how visual working memory (VWM) performance is affected by these competitive interactions. Here, we presented participants with memory displays in low- or high-competition configurations by manipulating the distance between objects. Participants responded by selecting from a colour-wheel the colour of the probed location. Using a three-component model described by Bays and colleagues (Bays, Catalao, & Husain, 2009), we describe the effects of competition on the number and precision of VWM representations. That is, in addition to examining correct responses, the proportion of non-target errors was examined. The results demonstrate that the fidelity of VWM responses is negatively affected by competitive interactions, as response precision decreases when the competition between sam-

ple items increases (i.e., when they are presented close together). Specifically, competitive interactions increase the number of non-target errors, but without affecting the number of targets correctly reported. Thus, increasing the competition between items appears to increase the amount of response error by biasing responses towards non-target items, without affecting the number of items stored in VWM. Furthermore, we demonstrate that target responses can benefit from attentional cues, indicating that bias signals can support VWM encoding and maintenance by resolving competition. Interestingly, the precision of reporting a single object is strongly correlated with VWM capacity, suggesting that VWM capacity may be related to the quality of perceptual representations. These results provide a novel framework for understanding performance limitations in VWM.

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63.403 Perceptual grouping enables multiple items to be stored within a single slot in visual working memory

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Resolution in visual working memory (WM) declines monotonically with set size. Discrete resource models account for this relationship by positing a fixed set of slots that constrain the allocation of the resources that determine WM resolution. Critically, the discrete view predicts that precision will reach a stable asymptote once the item limit is exceeded because resources are allocated only to stored items. In line with this prediction, we recently observed that precision in an orientation WM task reached asymptote at a set size that was strongly predicted by behavioral and neural estimates of each observer's item limit. Here we used the same approach to examine whether perceptual grouping cues enable multiple items to be represented within a single slot. We measured WM performance in an orientation recall task using solid discs containing prominent gaps. On half of the trials, the gaps in pairs of items were collinear with respect to each other, such that an illusory rectangle was formed (grouped condition). Orientation was random during the other half (ungrouped condition). As in the previous work, WM precision reached a stable asymptote at a relatively low set size. Moreover, the set size at which this asymptote was achieved was approximately doubled in the grouped condition, suggesting that multi-item perceptual groups can be stored within a single discrete slot in visual WM. Across the grouped and ungrouped conditions, there was robust correlation between the set sizes at which asymptote occurred, suggesting that these asymptotes were the product of the same fixed item limit. Thus, the assignment of visual items to discrete slots in memory is done on the basis of scene-level representations that are sensitive to Gestalt grouping cues, rather than image-level representations in which each disc is individuated in visual WM.

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63.404 Competition for working memory resources depends on the kind of stimuli being remembered

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The limits of visual working memory have been well established for simple colored shapes, where it is typically assumed that all stimuli compete equally for this limited memory resource. Here we examined whether different stimulus categories (faces, bodies, objects, scenes) draw equally on working memory resources or if the kind of stimuli to be remembered show more or less competition for memory storage.

Participants performed a change detection task in which four items were presented on the screen. Following a short delay, the display reappeared with a single item cued and observers indicated whether or not that item changed. Four items from the same category were presented (e.g. four scenes or four faces), or two items from two categories (e.g. two faces and two scenes). For each pair of categories, performance was compared between remembering four items from the same category and the mixed category trials.

Overall, we found a "mix effect": performance with two categories was systematically higher than performance with only one category. Interestingly, the effect was graded: three different pairs of stimuli — Faces/Scenes, Bodies/Scenes, and Faces/Object — yielded a large mix effect (Cohen's $D > 1.7$), while other pairs — Faces/Bodies and Objects/Bodies — yielded a smaller mix effect (Cohen's $D > 0.6$). Only the Objects/Scenes pairing did not show an increase in performance in the mix condition (Cohen's $D < .1$, $p = 0.84$).

This pattern of results is generally consistent with the similarity of patterns of activation observed across the ventral visual cortex for these categories. These results demonstrate that the capacity of visual working memory depends on what is being remembered, and suggest that the amount of information that can be stored increases as a function of the independence of the underlying neural resources used to encode that information.

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63.405 Capacity & Resolution Trade Off in Iconic Memory but not in Working Memory

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The storage capacity of visual working memory (VWM) is strongly correlated with broad measures of cognitive abilities, but the nature of capacity limits has been the subject of considerable controversy. Some researchers have proposed that VWM stores a limited set of discrete, fixed-resolution representations, whereas others have proposed that VWM consists of a pool of resources that can be allocated flexibly to provide either a small number of high-resolution representations or a large number of low-resolution representations. To distinguish between these possibilities, we tested whether observers can, depending on task demands, store either a larger number of coarse-grained representations or a smaller number of fine-grained representations. The flexible resource hypothesis predicts that observers should be able to strategically trade off resolution for capacity. In contrast, the fixed resolution hypothesis predicts that VWM resolution and capacity are not under strategic control.

We used a color recall task in which observers attempted to retain several colors in VWM over a 1-s retention interval and then recalled one of them by clicking on a color wheel. Task demands for VWM precision were manipulated in different ways in three experiments. For example, high precision was necessary when the color wheel contained 180 continuously varying colors, whereas low precision was sufficient when the color wheel was divided into a small number of discrete color wedges. In addition, differential payoffs were used to reward either high capacity or high resolution. Across the three experiments, we consistently found that VWM resolution and capacity remained constant across conditions, supporting the fixed resolution slot hypothesis. In sharp contrast, observers could trade off capacity and resolution when iconic memory was tested by eliminating the delay between sample and test. Thus, working memory consists of a limited set of fixed-resolution representations, whereas iconic memory consists of a flexible resource.

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63.406 Visual working-memory capacity is unbounded

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Ever since Miller's (1956) seminal paper, a central tenet of the cognitive neurosciences holds that working memory (WM) capacity is severely limited, in most recent estimates typically to about four items. Limited working memory capacity estimates have mostly been found in experiments presenting participants with the same items in many trials. Therefore, participants must deploy filtering mechanisms to remember that a given test item was presented in the current trial rather than a prior trial. Consequently, capacity limitations might not reflect constraints on the number of items that can be placed in WM, but rather constraints on filtering processes when faced with interference from items in previous trials. Here, we show that, with new items on every trial, visual working memory capacity estimates are unbounded, whereas traditional capacity limits emerge if the same items reappear frequently across trials. In each trial of two experiments, participants saw a sequence of 5 to 21 pictures of familiar objects, presented in sequence for 250 ms per picture, and were tested on their recognition memory for these pictures. Crucially, participants were randomly assigned to one of two conditions. In the unique condition, all pictures were unique, and were encountered only once in the experiment. In the repeated condition, pictures were selected from a set of 22 pictures; participants thus saw the same pictures repeatedly across trials. Results showed that, in the repeated condition, WM capacity estimates remained in the range previously reported. In the unique condition, in contrast, we did not observe an upper bound to capacity estimates; the more items participants saw, the

more items they remembered. Visual working memory capacity is, therefore, not limited by storage constraints. Rather, capacity limitations arise from interference from previous trials when small sets of items are used.

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63.407 Forgetting in Visual Working Memory

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Recent research has shown that a directed forgetting cue can benefit visual working memory task performance nearly as much as a cue that indicates which items will be tested. What neural mechanisms underlie this benefit and how does it aid the memory representations that are retained? We addressed these questions in the present study by recording event-related potentials (ERPs) and using a recall paradigm to measure the nature of the retained memory representations. Our ERP findings show that when observers were given a cue to forget some information that they focused neural mechanisms of maintenance on the remaining information stored in visual working memory. By testing visual working memory with a recall procedure we show that this focused maintenance results in higher fidelity representations of the remaining items following a directed forgetting cue. Thus, the present findings show that cues to forget benefit the remaining information in visual working memory by focusing maintenance processes which then fundamentally improves the quality of those retained representations.

63.408 Sensory information in iconic memory can be used to improve decision-making.

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Simple decisions about features or properties of visual stimuli have been shown to involve a process of accumulating noisy sensory information over time, until a criterion amount of information has been attained and a decision can be made. High-resolution sensory information is accessible for several hundred milliseconds following stimulus offset (iconic memory), and may therefore act as a further source of evidence from which information is accumulated. In this study, we asked participants to make a series of simple judgments as to whether coherent motion in a random-dot stimulus was moving left or right (2AFC). Participants responded either immediately (speed-accuracy trade-off), after a varying blank delay (100-800ms), or after a masked delay (100-800ms). We found that when participant's post-stimulus responses were delayed by viewing a blank screen, decision accuracy improved for up to 400ms. However, when the blank screen was replaced by a sensory masking stimulus, which has been shown to interfere with iconic memory, accuracy was significantly lower. The results of this study suggest that we can continue to accumulate evidence from an iconic store in the absence of a physical stimulus, and hence improve decision accuracy. Furthermore, the rate at which evidence is accumulated from a memory representation of the stimulus was found to match the rate of evidence accumulation during stimulus viewing.

63.409 An Ensemble Group Functions As a Single Item for Attention and Memory

Justin Halberda¹(halberda@jhu.edu); ¹Psychological and Brain Sciences, Johns Hopkins University

In this talk I present experiments demonstrating that processing an ensemble group of many items requires a single "slot" in visual attention and visual working memory; an ensemble group functions as a single item. Experiments 1-3 used subitizing as an assay for studying the deployment of attention to both ensemble groups and individual objects. When subjects were asked to enumerate individual objects, the classic subitizing elbow was seen with rapid and accurate enumeration for 1, 2, and 3 objects and slower more error-prone enumeration above 3. When similar displays appeared containing ensemble groups of many items, this same result obtained with speed and accuracy depending on the number of groups present, not on the number of objects inside each group. In Experiments 2 and 3, known factors that interfere with subitizing (e.g., presenting concentric rings rather than spatially separated rings) were found to affect both objects (rings) and ensembles (groups of dots) to the same extent, further suggesting that each ensemble group behaves like a single item for visual attention. Experiments 4-6 used change detection and partial report measures of visual working memory capacity and found that each ensemble group requires a single "slot" in VWM and multiple ensemble features can

be stored for each group inside one slot (e.g., approximate number, average orientation, average size). Experiment 6 explored the time-course of consolidation of ensemble features in VWM and suggests that an ensemble is first selected as an item and then feature information is consolidated in parallel, similar to the consolidation seen for individual objects. These results inspire a reconsideration of the importance of selection prior to computing ensemble statistics and expand what can count as a single item for attention and memory.

63.410 Spatial working memory load affects counting but not subitizing in enumeration

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It is known that the reaction time for deciding how many objects comprise a scene typically remains roughly constant up to approximately four items but over which then increases linearly with the number of items. The enumeration consists of two components: subitizing as efficient enumeration for the small number (up to four items) and counting as the time-consuming enumeration for larger number. An outstanding question in studying enumeration processes is what determines the subitizing span. Present research investigated whether spatial or non-spatial visual working memory capacity is responsible for the subitizing span by manipulating memory load with a dual-task procedure. We compared the enumeration performances under memory load with those under no-load. Under the dual-task condition the dot-enumeration task intervened during 5,000 msec retention interval of a secondary memory task. Participants reported whether the memory item and the probe were identical in terms of location (Experiment 1) or shape (Experiment 2) after the retention interval. In the enumeration task, participants made a speeded response when they apprehend the number of dot and then reported the number at the end of the trial. Under the control single-task condition the memory task was omitted. The results showed that neither remembering locations nor shapes affected subitizing efficiency. Only counting efficiency was impeded when spatial memory load was imposed. Non-spatial memory load did not impair the counting efficiency. The subitizing span estimated by fitting a bilinear function was not decreased by both types of the memory load. Subsidiary experiments in which the amount of memory load was varied revealed that subitizing efficiency and span were unaffected by the increase of memory set size. These results suggest that subitizing span reflects neither spatial nor non-spatial working memory capacity. Rather, independent limitations are involved in subitizing and visual working memory.

63.411 Correspondence problems limit visual working memory

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We propose that fixed imprecision in representations of location produces correspondence problems that constrain working memory performance. To test this hypothesis, we replicated Bays & Husain (2008). Participants briefly saw 1-6 colored squares followed by a single probe horizontally offset. Reports on the direction of an offset varied probabilistically with its magnitude, and response functions were fit with a cumulative Gaussian distribution. As in previous work, the reciprocal of the estimated response function SD declined with increases in memory load. We suggest that this did not reflect a decline in precision, but an increasing probability that the location of the probe item was compared to the wrong memory representation – a correspondence problem failure. Consistent with this hypothesis, fixing the total number of displayed items at 12, while varying the subset to-be-remembered, depressed precision and rendered it invariant by load. Similarly, we found unchanging precision for a colored singleton among an increasing set of uniform items, though the singleton was no more likely to be probed than any other item. Critically, in another experiment, a preview display appeared quickly just before test, consisting of all items except the to-be-probed one. This manipulation, which solved any correspondence problem, resulted in unchanging precision as a function of load. Further experiments found unvarying precision at larger loads (6-8) when a preview was made available; that the gains accrued by previewing items depended on their distances from the probe; and that the precision of orientation memory likewise remained fixed when location previews were available. Collectively, these results imply that measured limits on working memory performance reflect failures to compare current states of the world

with the right pieces of stored information. Such correspondence failures emerge because memory is imprecise, but the degree of imprecision is fixed by inherent limitations on visual processing.

63.412 Visual working memory performance with contrast and external noise: A load-dependent perceptual template model account.

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Visual working memory (VWM) has been extensively investigated using a change-detection paradigm and a High Threshold (HT) model in which stimuli are encoded and remembered perfectly up to a capacity limitation, and observers guess otherwise. However, the visual system does not function flawlessly and is limited by various sources of internal and external noise. Wilken and Ma (2004) used a signal detection theory (SDT) approach to model VWM performance at high contrast, and suggested that performance was limited by internal noise that increases with display size. Their experiment provided only modest constraints on the estimation of internal noises. The external noise approach, i.e., joint manipulations of the amount of external noise (white Gaussian random noise) and contrast of signal stimuli (oriented Gabor patches), provides a more stringent test of Wilken and Ma's claims and sufficient constraints on observer models. Observers detected a 45° change in the orientation between sample and test displays with 1, 2 or 4 randomly oriented Gabor objects in either clear or noisy displays. Contrast psychometric functions were measured and modeled with the perceptual template model (PTM) of the observer (Lu & Doshier, 2008). Noise terms associated with stimulus enhancement and external noise exclusion (often associated with attention) varied with display size in the VWM task. Our results extend and provide explicit measurement for Wilken and Ma's (2004) claim that VWM performance is limited by internal noises that increase with display size; the finding that the impact external noise increases with display size suggests that stimulus encoding also deteriorates with memory load. We also consider a HT model. The PTM observer model provides a natural context within which to understand the functioning of VWM in a broad range of stimulus conditions.

63.413 Using color cues to probe the influence of grouping in visual working memory for spatial locations

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Previous experiments have demonstrated that cues can sometimes have similar effects in visual attention and working memory (Griffin and Nobre, 2003). This experiment compared the effects of cues on items that can be grouped into larger units or isolated individually by color. Each stimulus consisted of 5 colored dots placed randomly in a fixed area in the center of a computer screen for 1.5 seconds. The dots were either 5 different colors, or 4 dots of the same color and 1 dot of a different color. Auditory cues for one color were presented either simultaneously with the visual stimulus, immediately after the stimulus vanished, or 2 seconds later. Approximately 2-5 seconds after the visual stimulus was presented, participants were shown a blank screen and asked to click the location where the cued color had been displayed earlier in the trial. For cues presented simultaneously with the stimulus, the distance clicked from the target was equivalent in all conditions. Compared to simultaneous cues, in trials with retrocues, distance increased across all conditions, but increased significantly more in the condition with 5 unique colors. In the two-color condition, no difference was found when a singleton was cued compared to cueing any of the 4 same colored items. These results are consistent with the hypothesis that grouping based on color may be used within visual working memory to increase visual acuity for location.

63.414 Individual differences in VWM capacity assessed by the flicker task

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Here we demonstrate that the flicker change detection paradigm provides a more stable estimate of individual differences in visual working memory (VWM) capacity than the more typical "one shot" paradigm. Recent excitement has surrounded the drive to understand individual differences

in VWM capacity, as these differences may be a locus for broader impacts throughout cognition. In our study, participants completed 240 or 480 trials of either a one shot or a flicker task, during which they were presented with displays containing 2, 4, or 8 colored squares. The one shot condition used standard parameters from published papers and capacity was estimated using Cowan's K. In the flicker condition, participants saw these same displays with the memory and change displays alternating until the changing stimulus was found and capacity was estimated using Rensink's RT-based estimate. Capacity estimates were generated for each set size and compared. Reliability of capacity estimates were assessed via split-half correlation and revealed significantly higher reliability for flicker than for one shot. Dramatically, after 10 minutes of testing (the amount used in many published papers with the one shot task), split-half correlation for one shot was non-significant ($R^2 = .01$), suggesting little to no reliability in its estimate of individual differences in VWM capacity, while split-half correlation for flicker was significant ($R^2 = .63$). When the number of trials in the task was doubled, one shot began to produce significant split-half correlations. A likely source of the difference between these tasks is that the flicker task requires the subject to deploy VWM capacity many times during a single trial allowing for a more stable estimate of VWM capacity. Concerns about search behavior in the flicker task remain (e.g., is it random with or without replacement or something in between) and further comparison of these two paradigms seems warranted.

63.415 Working memory capacity predicts individual differences in perception of a bistable figure

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Individual differences in working memory capacity (WMC) correlate with an ever-growing number of cognitive tasks. These individual differences are thought to predict performance because they tap into variation in executive attention. A little-explored question, however, is to what extent individual differences in WMC might account for performance in "lower level", more perceptual tasks, where a requirement of attentional control may be less apparent (e.g., Allen, Beilock, & Shevell, VSS 2009). This study investigated whether individual differences in WMC are related to individual differences in perception of a bistable figure.

Participants viewed a Necker cube on a computer screen with a fixation cross at its center, and indicated when their percept alternated during several 3-min trials. Dominance duration (average elapsed time between a perceptual alternation) was measured under four conditions (Kornmeier, Hein, & Bach, 2009). In the passive condition (always completed first), participants were simply told to report their alternations. In the hold-unspecific condition, participants attempted to hold whichever percept was currently dominant. In the hold-specific condition, participants attempted to hold a specified percept. In the reverse condition, participants attempted to alternate their percept as often as possible. WMC was measured using the RSPAN task (Daneman & Carpenter, 1980).

WMC was positively correlated with dominance duration in the passive and hold-unspecific conditions, and negatively correlated with dominance duration in the reverse condition and for the non-specified percept in the hold-specific condition. These results are expected if individual differences in WMC are related to the ability to exert "top-down" attentional control to increase or decrease the dominance duration of a bistable figure. Moreover, results from the passive condition demonstrate the relation with WMC holds without any goal-directed task, suggesting a "lower-level" perceptual process; in addition, this result provides a possible mechanism for the often-reported individual differences in dominance duration for passively viewed bistable figures.

Acknowledgement: Supported by NIH grant EY-04802 to S.S. and NSF CAREER award DRL-0746970 to S.B.

63.416 **Contralateral delay activity during visual working memory reveals not only number but also precision of maintained representations**

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Research on visual short-term memory debates whether a fixed number of 'slots' or instead the precision of maintained information restricts performance. We tested participants on visual-orientation working memory. For each trial a brief sample display presented two or four oriented bars within each visual hemifield; one hemifield was precued for retention at trial start. After a delay of 1.5 seconds, participants judged whether a single probe bar was rotated clockwise or anticlockwise from the sample orientation shown at that location prior to the delay. The change in orientation could require more precision (15 degrees) or less precision (45 degrees) for the comparison. The color of the sample display indicated on each trial which precision was most likely. Behaviorally we found that rarer trials with 30 degrees of actual change (occurring on one third of trials) were judged better when more rather than less precision was anticipated; but only with the lower set-size of 2 items. This shows that the precision retained can be varied at will, provided set-size is low. Two related EEG experiments revealed that the well-known 'contralateral delay activity' (CDA) component during the delay period was higher not only for set-size four than two, but also higher for two items in the high-precision than low-precision conditions. These results support the emerging notion of dynamic allocation of limited capacity in visual working-memory, while showing that CDA can provide a neural marker for retained precision as well as retained set-size.

Acknowledgement: Wellcome Trust

63.417 **Estimates of working memory capacity reflect recall precision not how many items are stored**

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The ability to detect a change to a remembered array of visual objects has become the predominant experimental measure in the study of working memory, whether investigating its basis in neurophysiology, its development and decline over the lifespan, or its impairment due to brain damage or disease. The dominance of this methodology relies on a simple interpretation of the frequency of errors as reflecting a limit on the number of items (K) that can simultaneously be maintained in visual memory. Here we show that performance on the change detection task does not measure a fixed maximum capacity of working memory, but instead reflects methodological details of the experimental design. Parametrically manipulating the distance in feature space between changed and unchanged items causes the estimate of capacity to vary from $K < 1$ to $K > 5$ items. The results of previous influential studies that have estimated capacity at about 3 items can be directly predicted from the stimulus distances employed in those tasks. While inconsistent with a fixed item limit, our results are accurately described by a Bayesian implementation of a shared-resource model of working memory, in which all items are stored but with a variability that increases with total memory load. This model provides a superior fit to a range of previous results, including the variability in change detection between individuals, changes in performance during development, and classic results from 'whole report' of visual or auditory arrays.

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63.418 **Neural measures reveal similar capacity limits for both present and absent information**

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In most visual working memory (WM) paradigms, subjects must remember a briefly-presented set of items across a blank retention period of one or more seconds. A common finding is that most subjects can accurately maintain about three items simultaneously. In this study, we examined whether these capacity limits are exclusively for maintaining items that are no longer present, or if similar limitations are observed for items that are continuously visible. To do this, we presented subjects with displays of simple objects and asked them to remember the colors of each item until the presentation of a test probe that appeared at the position of one of the items. The memory array was presented for either 100ms, 500ms, or 1000ms, which resulted in blank retention intervals of 900ms, 500ms,

or 0ms. Surprisingly, we found both behavioral and electrophysiological evidence that the capacity limitations and neural mechanisms supporting performance (contralateral delay activity) were equivalent for displays in which the items were either not present during the retention interval or were continuously visible to the subject. These results suggest that capacity limits for simultaneously representing multiple items are not exclusive to WM maintenance of information that is no longer there, but also extend to perceptually present items.

63.419 **Individual differences in the ability to restrict the breadth of attention are correlated with visuospatial working memory capacity**

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There is substantial evidence for a close relationship between attention and working memory (WM; e.g., Jonides et al., 2008). We therefore hypothesized that individuals with relatively high WM capacity are better able to restrict the focus of attention to relevant spatial locations. Findings from a separate line of research (e.g., Castiello & Umiltà, 1990; Turatto et al., 2000) indicate that the efficiency with which stimuli appearing within the focus of attention are processed is inversely related to the size (breadth) of the attentional focus, which has been manipulated by spatial precues of variable size. Thus, the magnitude of this cue-size effect indexes the effective concentration of attention to the relevant spatial location. If people with relatively high WM capacity are better able to restrict attention to a relevant spatial location, then there should be a positive correlation between WM capacity and the magnitude of the cue-size effect. Our results confirmed this prediction, indicating that visuospatial WM capacity and the ability to restrict the distribution of visuospatial attention (even when only a single location is relevant) are correlated across individuals. These results also are consistent with the possibility that the ability to constrain and maintain attentional focus underlies the increased precision of WM representations observed for high-capacity individuals (e.g., Walsh, Gmeindl, Flombaum, & Shelton, 2010).

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63.420 **Capacity and resolution for approximate number in perception and memory**

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Approximate number of items in a group is an ensemble feature. Extracting number information from a group takes time and involves both perceptual and memory processes. It is unclear how limited cognitive resource and capacity is allocated among multiple groups to extract their approximate numbers. Is there a tradeoff between the quality and the quantity of encoded number representation? That is, is encoding number information from one group faster and more accurate than multiple groups? Here we show the surprising result that there is little or no cost for enumerating two groups in parallel. On each trial, one, two, or four sets of dots (number of dots per set range: 5-25) in different colors were briefly presented and followed by masking sets of dots with variable stimulus onset asynchrony (SOA, 33, 67, 100, 133, or 217 ms). One of these sets was cued with a circle. Participants estimated the number of dots in the cued set by clicking on a continuous number scale. We found that resolution of number representation increased over time, especially for shorter SOAs, suggesting a gradual accumulation process. The accumulation of two sets was as accurate and fast as the accumulation of one set. The accumulation slowed down for four sets of dots. Our findings support a parallel processing of numerosity of multiple sets in perception, in sharp contrast to a serial consolidation process in visual working memory at a later stage.

63.421 Visual Working Memory for Motion Sequences

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The cognitive mechanisms of visual working memory for sequentially presented objects are not fully understood. We investigated the precision of memory for motion direction of sequentially presented colored objects. Observers viewed random dot motion stimuli displayed sequentially at fixation. Within a sequence, each stimulus was displayed in a different color. At the end of each sequence, participants were asked to adjust a colored probe's direction to match the direction of motion of the stimulus with the same color. We quantified precision as the reciprocal of the standard deviation of error in response direction. The results show a decrease in precision for motion directions presented within longer sequences. There was a significant effect of serial position of the target within each sequence; the last item was remembered best. Importantly, this recency effect was influenced by the number of preceding items; precision of memory for the last item was lower when presented in longer sequences. We applied a probabilistic model of performance to integrate possible sources of error in memory. The model takes into account possible changes in variability in memory for target direction, the probability of responding to a non-target direction and the probability of responding at random. The fall in precision for the last item presented in longer sequences was purely explained by an increase in variability in memory for target direction in these sequences. A similar decrease in precision within longer sequences was observed in other serial positions of the target. This was explained by an increase in probability of responding to a non-target motion direction. These results are compatible with a dynamic resource model of memory whereby a limited resource is shared between items presented in a sequence. The amount of memory allocated to each item is affected by the preceding items and the items that follow it.

63.422 The Effect of Visual WM Capacity on Attentional Selection

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Attention can be directed voluntarily by goal relevant information or it can be captured involuntarily by perceptually salient input. For example, the maintenance of target information in working memory (WM) can facilitate strategic allocation of attention to an item that fits target criteria or away from items that fail to meet target criteria (Woodman & Luck, 2007). Similarly, eye movement data suggests that top down attentional selection can be controlled when individuals know that a perceptually salient object cannot be the target (Geng & DiQuattro, 2010). We measured individuals' visual WM capacity using a modified version of the change detection task (Luck & Vogel, 1997). Then we examined individuals' performance and eye movements in a visual search task where a cue provided information about the salience of either the target or distractor on a trial-by-trial basis. High-capacity individuals demonstrated greater ability overriding attentional capture than low-capacity individuals, particularly when the cue indicated that the distractor was salient. More specifically, low capacity individuals were more likely to saccade to a salient distractor first when it was cued. This suggests that distractor salience information held in WM biased low capacity individuals to erroneously select the distractor. Low capacity individuals also had shorter saccade latencies when the first saccade was captured by the salient distractor, indicating oculomotor capture. In contrast, there were no significant differences in these saccade parameters in high capacity individuals. Moreover, high capacity individuals responded faster than low capacity individuals in target-first trials when just the distractor was salient. We conclude that low capacity individuals are more prone to oculomotor capture by salient distractors despite information stored in WM whereas high capacity individuals are able to manipulate information in WM based on task context to optimize behavior (e.g., WM representation is related to the distractor, not target).

Attention: Emotion

Wednesday, May 11, 8:15 am - 12:15 pm
Orchid Ballroom, Poster Boards 423 - 430

63.423 Angry faces hold the eyes only to be avoided later: evidence from inhibition of return

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Efficient processing of complex social and biological stimuli associated with threat is crucial for survival. At present there are two major hypotheses about attentional deployment to the threat-related stimuli (Weierich, Treat & Hollingworth, 2008). According to the vigilance-avoidance theory threatening stimuli initially capture attention, but are avoided at the later stage. According to the delayed disengagement hypothesis threatening stimuli do not capture attention, but if attended they are monitored more extensively and delay disengagement of attention from their location. To resolve this controversy the present study employed a novel paradigm that allowed us to measure the disengagement and avoidance using eye movements. In the first experiment we showed that participants were slower to make an eye movement away from an irrelevant angry face presented at fixation than from either a neutral or a happy face. This finding supports the notion that delay in disengaging attention from threat is an important component of processing threatening information. To relate the disengagement to avoidance in a follow-up experiment participants were asked to make a saccade away from a face, but on some trials they were also asked to either return their gaze to the face or to make an eye movement to a new location. These "return" saccades were expected to be executed slower than saccades to the new location due to the well-known inhibition of return (IOR). The question was whether IOR would be greater for the angry faces. The results showed that participants were again slower to disengage the eyes from an angry face but importantly, the IOR was greater for angry faces suggesting that participants avoided returning their gaze to the angry face. The results provide a first demonstration of a direct link between the delayed disengagement and avoidance of threatening stimuli and bridges the gap between the two major theories.

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63.424 Does the Threat Advantage Hypothesis Extend to Static Body Postures?

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The Threat Advantage Hypothesis posits that observers preferentially attend threats. Evidence supporting this hypothesis comes from point-light walker detection studies in which observers are best able to detect the presence of angry point-light walkers in a mask (e.g., Chouhrouelou et al., 2006). Support also comes from numerous visual search studies in which the detection of angry and fearful faces is superior to the detection of other affective faces (e.g., Ohman et al., 2001). However, visual search studies with faces are far from uniform in their support of the threat advantage hypothesis (e.g., Horstmann, 2009). If static facial expressions, per se, present a particular challenge to the threat advantage hypothesis, then other stimuli may yield clearer evidence. To that end, a series of detection studies was performed with static, affective body postures. Computer-generated static emotional body postures were created. To validate and norm the stimuli, 17 naïve observers sequentially viewed each stimulus and reported with a button press which of 4 emotions was depicted. Then, a visual search task using the normed postures (angry, fearful, sad, neutral) was conducted. In each display, six affective body postures were positioned around a 25.0 DVA circle centered on fixation. 20 new naïve observers reported whether an oddball posture was present. Oddball detection was not selectively speeded for threat relevant postures. In a second study, 23 new observers viewed these stimuli and reported whether a specific affective posture was present. Again, the detection of threat relevant postures was not speeded. Subsequent studies using different methodologies (e.g., dot probe) have yet to identify speeded detection of threatening postures. These and other results suggest that the threat advantage hypothesis is not uniformly supported by static cues to threat, whether facial or bodily. Instead, movement may be a more powerful cue to threat.

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63.425 On the time course of exogenous cuing by the emotional faces

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Threatening stimuli can have effects on attention have been supported by previous studies. In the cuing task, using an angry face as the cue was found to slow down the response compared to the neutral face condition in invalid trials. In another respect, angry face as the cue was found to decrease the IOR effect in longer SOA. But there were still inconsistent results among different studies. In the present study, SOA between the face cue and the target was manipulated (150, 300, 500, 1000ms) within participants to reveal the time course of the cuing effect. Three kinds of schematic faces (angry, happy and neutral faces) were included as the exogenous cue. The face cue was presented for 100ms. Then the target was presented in the cued region (valid trials) or uncued region (invalid trials) after appropriate delay depending on the SOA conditions. The ratio of valid/invalid trials is 50/50. Participants' task was to discriminate the shape of the target (circle or square) and respond by key-pressing accordingly. The results showed that SOA curves were rather similar among three face cues with validity effect in shorter SOA (150, 300ms) but not in long SOA (1000ms). IOR effect has not been found in this study. On the other hand, angry face condition also showed validity effect at SOA=500ms, but not in happy and neutral face conditions. In addition, for the invalid condition, SOA curve of the angry face cue has shortest reaction time at 300ms, while other face cues has shortest reaction time at 500ms. Therefore, angry face cue has a different time course from other face cues. In conclusion, although the cuing effect of the neutral and emotional faces may be similar in most of the time windows, there is difference among them in the critical time window.

63.426 Do Observers' Negative Self-Evaluations of Their Own Bodies Mediate Their Visual Attention Towards Other Bodies?

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Background: Previous research suggests that spatial distributions of attentional resources reflect the potentially rewarding and threatening characteristics of stimuli. Here we investigate whether psychological characteristics of the observer, namely, dissatisfaction with one's own body, systematically impacts distributions of attention within social scenes. Glauert et al. (2010) demonstrated that female observers exhibit attentional biases toward the bodies of thin women. We investigated whether this effect is limited to bodies, extends to male observers, and correlates with each observer's body dissatisfaction (BD) and/or body mass index (BMI). Methods: BMI was calculated from height and weight measurements and BD was assessed with the Body Satisfaction Questionnaire BSQ-34. Male and female observers completed a modified dot probe task to assess attentional distribution across space. After fixation, two bodies of the same gender (one thin, one overweight) appeared simultaneously one above the other. After 500ms, the bodies disappeared and an arrow appeared in the previous location of one of the bodies. Participants reported arrow direction with a key press. Reaction times in correct trials were analyzed to determine whether observers showed an attentional bias toward thin bodies. In a control condition, thin and heavy bodies were replaced with narrow and wide objects (buildings or bottles). Results: Female, but not male ($p > .05$), observers showed a significant correlation between attentional bias towards thin bodies and BD $r(87) = .234, p = .027$. Attentional bias did not correlate with BMI nor was it found with objects (all $ps > .05$). Conclusions: The strong relationship between attentional bias towards thin bodies and body dissatisfaction in female observers supports the hypothesis that psychological characteristics of observers impact their spatial distribution of attentional resources across social scenes. Indeed, this bias may reflect a perceptual mechanism that maintains body dissatisfaction.

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63.427 Emotion-induced blindness elicits no lag-1 sparing

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Emotional stimuli can hinder awareness of subsequent stimuli presented in an RSVP stream. Known as emotion-induced blindness, this phenomenon bears considerable likeness to the attentional blink (AB), as in both cases attention to an initial item impairs detection of a subsequent item.

One account of perceptual failures in RSVP suggests that they can arise due to spatiotemporal competition, where rapidly presented items that overlap in space elicit neural responses that also overlap in time (Keyers & Perrett, 2002), and recent evidence suggests that such competition might contribute to emotion-induced blindness (Most & Wang, in press). However, such a mechanism cannot account for "lag 1 sparing", the preserved perception of the first item that follows an initial target in many AB studies. Given the phenomenological similarity between emotion-induced blindness and the AB, we investigated whether lag 1 sparing occurs in an emotion-induced blindness task. In Experiment 1, participants searched for a target (a rotated landscape image) embedded within a rapid serial stream of upright landscape photos and tried to ignore task-irrelevant neutral or emotional distractors that could appear either 1 (lag 1) or 2 (lag 2) serial positions prior to the target. Emotional distractors impaired target perception equally at lag 1 and lag 2, indicating an absence of lag 1 sparing. In Experiment 2, we compared performance at lag 1 to performance at lag 8 in order to confirm that such emotional disruption stemmed from a perceptual bottleneck rather than a performance decrement that generalized across lags. Consistent with disruption of perceptual processing, emotion-induced blindness occurred at lag 1 but not lag 8. Together, these results support the notion of spatiotemporal competition as a mechanism underlying emotion-induced blindness.

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63.428 Pick me! Pick me! How do humans forage in a visual search task?

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Foraging tasks like berry picking are extended visual search tasks with good berries as targets. Many real-world tasks have foraging structures (e.g. looking for military infrastructure in satellite images of Afghanistan). Back in the raspberry field, you would typically abandon search of one area before every berry was picked. Optimal foraging theory (Charnov, 1976) proposes that animals leave a patch when the yield from that patch drops below average yield. This calculation is modified by transit time to the next patch: stay longer if transit time is longer. We created an 8x8 field of patches. Each patch contained 8-64 "berries". "Good" berries were probabilistically bigger and redder than bad berries ($d' = 2$). Observers selected a patch to forage. They clicked to pick and received auditory feedback about the goodness of the clicked berry. They could leave for another patch whenever they liked. They tried to maximize points (hit=+1, false alarm=-1) in 10-minute blocks. Picking rate was varied (easy vs hard) by making it unnecessary or necessary move the cursor around obstacles and transit time could be slow or fast (=10Xslow). In a patch, initial picks were about 85% successful across all four conditions. Observers abandoned the patch when success fell to about 70% when picking was hard. They persisted to about 50% when picking was easy. When transit speed was fast, observers picked the next patch on the basis of apparent density of resource no matter how far away. At slow transit speed, observers tended to move to nearest neighbors. Observers maintained a constant rate of berries/second within a ten-minute block. In each patch, the berries/second rate drops as the berries become scarce. Observers appear to leave the patch when the instantaneous rate drops below the average rate for the block - exactly as Optimal Foraging Theory predicts.

63.429 The influence of aversive natural images on visual processing and awareness

Anke Haberkamp¹(haberkamp@sowi.uni-kl.de), Kathrin Niederprüm¹, Thomas Schmidt¹; ¹School of Social Sciences, Psychology I, University of Kaiserslautern

In a recent response priming study, we found that spider pictures lead to faster visuomotor processing in spider fearful participants, compared to snake or neutral pictures (Haberkamp, Schmidt, & Schmidt, in preparation). We assume that these findings are due to perceptual learning processes, more specifically to 'hardwired binding' of spider features, in spider fearful participants. We hypothesize that spider fearfuls should also outperform non-anxious control participants in their ability to detect masked spider primes (i.e., their visual awareness of the primes). Therefore, we applied a masking paradigm: in each experimental trial, one prime and target, chosen randomly from one of four stimulus categories (spiders, snakes, mushrooms, flowers), were presented in rapid sequence. In half of the trials the prime was masked by a 1/f noise mask. In the first four experimental sessions, participants performed speeded keypress responses to classify the

targets ('Target ID'). In the second four sessions participants tried to identify the masked or unmasked primes ('Prime ID'). In both identification tasks, participants performed two classification tasks: They either discriminated spiders and snakes from flowers and mushrooms ('animal vs. non-animal task') or spiders and mushrooms from snakes and flowers ('snake vs. spider task'). Results in non-phobic participants showed strong and reliable priming effects in the 'Target ID' task in both conditions and a strong influence of the mask in the 'Prime ID' task. These results will be compared with those of spider fearful participants to draw conclusions about image processing of fear-relevant stimuli in anxious participants.

Acknowledgement: German Research Foundation

63.430 The Emotional Blink in Novice Meditators

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Attention and emotion are linked in critical ways. Emotionally salient objects attract and capture attention. Attention to emotional stimuli influences emotion processing and regulation. Meditation techniques have been used for millennia both to train attention and to regulate emotion. A common meditation practice involves sustained attention on the breath. Slagter and colleagues (2007, PLoSBiology) showed improved performance and concomitant brain potential effects during an attentional blink task in experienced meditators after a 3-month meditation retreat. We ran an "emotional blink" task with novice attention-to-breath Zen meditators and students without meditation experience. Twelve targets consisted of 3 different male faces expressing neutral, happy, angry, or sad emotions. Two faces, always differing in identity, were targets (T1 and T2). Both were neutral (the control), or T1 was emotional and T2 neutral, or T1 was neutral and T2 emotional. Distractors were different male neutral faces shown inverted. Participants identified the two upright faces in the RSVP stream by selecting them from the set of faces after each trial. Overall performance was superior in meditators compared to controls, whereas attentional-blink magnitude was similar for the two groups. In addition, when T1 was emotional, T1 performance improved relative to neutral for both groups; T2 performance deteriorated for meditators, but not for controls. In contrast, when T1 was neutral and T2 emotional, T1 performance did not differ from the neutral baseline for meditators, but was impaired for controls, possibly due to distraction from the emotional T2 face. T2 performance improved for both groups but more so for meditators than controls. For these students, meditation experience improved their attention to the task, and also heightened their perception of emotional faces, but did not allow them to disengage from those emotions more efficiently.

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Attention: Reward

Wednesday, May 11, 8:15 am - 12:15 pm

Orchid Ballroom, Poster Boards 431 - 435

63.431 Interactions between Reward, Feedback, and Timing Structures on Dual-Target Search Performance

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Individuals who conduct visual searches that can contain more than one target face many challenges. Such multiple-target visual searches can be especially error prone, as identification of one target often makes identification of a second target less likely. Given that many real-world searches can be multiple-target searches (e.g., radiological examinations, baggage screening, military searches), it is important to understand what can affect performance. Multiple-target search is particularly sensitive to top-down influences such as anticipatory anxiety (Cain, Dunsmoor, LaBar, & Mitroff, VSS 2011), and here we explore the impact of reward motivation. Participants completed a paradigm that reliably produces dual-target errors (Fleck, Samei, & Mitroff, 2010). When we simply motivated participants with a performance-based, ten-percent chance of winning an additional \$50 in compensation (Experiment 1), the performance decline on dual-target trials was eliminated, while accuracy on single-target trials remained the

same. Further, without monetary motivation, adding trial-by-trial feedback (Experiment 2) did not significantly improve dual-target accuracy; however, the presence of both monetary motivation and feedback (Experiment 3) resulted in substantial performance benefits for both single- and dual-target conditions compared to Experiments 1 and 2. Finally, in the presence of top-down monetary motivation, trial-based time limits (Experiment 4) did not affect performance (i.e., participants performed equivalently with or without a time limit). This is in contrast to prior data without monetary incentives (Fleck et al., 2010), in which time limits negatively affected performance. Collectively, these experiments demonstrate that (1) motivation alone is sufficient to enhance dual-target search performance, (2) such benefits are enhanced when paired with trial-by-trial feedback, and (3) time limits hurt performance in the absence of motivation but have no effect with motivation. These findings provide key information about the role of top-down motivation on performance and how this can successfully improve performance on critical dual-target searches.

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63.432 Prosaccades and antisaccades under risk: penalties, rewards, and their spatial effects.

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Background: Recent monkey studies suggest that the spatial location of reward cues influences saccadic programming, even when reward is not contingent on the location of the target and the saccade. This has been interpreted as an effect of reward operating through modulating attention in cortical areas involved in saccade generation. Objective: We examined human saccades to determine a) if reward and penalty differed in their effects, b) if these effects were greater in more cognitively demanding saccades, and c) if the contingency of financial consequences on stimulus location had spatially selective effects. Methods: Human subjects made prosaccades or antisaccades after motivational cues indicating if correct responses would be rewarded, incorrect ones penalized, or neither. In non-contingent sessions, financial consequences applied regardless of stimulus location, while in contingent sessions, they occurred only when the stimulus or response was at the same location as the motivational cue. Results: Financial motivation generally resulted in shorter latencies. This effect was similar for prosaccades and antisaccades, and greater for reward than for penalty. Motivation also improved antisaccade accuracy. However, while non-contingent sessions showed an inhibition-of-return-like effect for the location of the motivational cue, this did not differ between reward, penalty or neutral trials. When financial consequences were contingent on location, locations without financial consequences lost the benefits in reaction time and accuracy seen in non-contingent trials, while the locations with financial consequences maintained these benefits but did not show further gains in performance. Conclusions: Reward is more efficient than penalty in enhancing saccadic performance and this is similar for both automatic prosaccades and cognitively demanding antisaccades. With motivation, the saccadic system can not only enhance responses to multiple locations simultaneously, but also optimize movements only to locations where financial consequences apply, and not to those where they do not.

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63.433 Expectations alter the neural correlates of visual awareness in visual cortex

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Top-down processes are well known to modulate sensory awareness. For example, endogenous attention enhances the access of visual information to awareness and is associated with increased neural activity in visual cortex. However, it is less clear whether top-down modulations alter the contents of awareness in a qualitative manner. We addressed this question by testing the effect of learned expectations on the neural correlates of visual awareness during bistable motion perception. In an fMRI experiment, participants viewed a random-dot-kinematogram perceived as a rotat-

ing sphere. During an initial baseline phase the stimulus was completely ambiguous, thus yielding bistable perception. Perceptual expectations were then induced in a subsequent learning phase, during which participants wore transparent glasses in two different orientations. Each orientation was associated with one dominant rotation direction of the stimulus, which was achieved by disambiguation through disparity cues. In the test phase we then probed how expectations associated with the glasses influenced perception of the ambiguous stimulus. We used multivoxel pattern analysis to decode perception from fMRI activation patterns in visual cortex. A support-vector-machine classifier was trained on the baseline runs to assign each scan to a reported percept, and was then used to predict perceptual states from activation patterns during the test runs. Reported dominance times for the expected rotation direction were longer than for the unexpected direction. Strikingly, this behavioural expectation effect was mirrored by the activations patterns in visual cortex: Decoding of the perceived rotation direction during test runs with a classifier trained on the independent baseline data yielded a significantly greater proportion of expected than unexpected percepts. This neural expectation effect correlated with the behavioural expectation effect, indicating that it indeed reflected participants' subjective perception. These results show for the first time that experimentally induced expectations alter the neural correlates of visual awareness in visual cortex.

63.434 Reward probability and magnitude in saccadic decisions under risk: measuring bias and sensitivity to expected value.

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Objective: Our goal was to evaluate how healthy subjects integrate information of reward magnitude and the likelihood of reward, to determine their threshold sensitivity to differences in value and their choice biases. **Background:** There are few clinical tests of decisions under risk. The most well-known, the Iowa Gambling task, assesses the ability to learn cumulative probabilities of gain or loss and to forego large rewards for smaller ones. However, tests that characterize sensitivity to expected value and biases between reward magnitude versus probability may provide insights in conditions with anomalous reward-related behaviour. **Design/ Methods:** Twenty subjects were required in 170 trials to choose between two explicitly described prospects, one having higher probability of reward but lower magnitude of reward than the other. The sizes of reward and the degree of probability were varied so that the difference in expected value between the two prospects varied from 3% to 23%. We first plotted choice as a function of expected value. Second, we used Prospect Theory to evaluate choice as a function of perceived value, using an exponential function for perceived reward utility and a single-parameter Prelec function for perceived probability. **Results:** Subjects showed a threshold sensitivity of 9.0% difference in expected value. Regarding choice bias, we found a 'risk premium' of 9.4%, indicating a slight tendency to choose higher probability over higher reward. Prospect Theory analysis showed that this risk premium is the predicted outcome of non-linearities in the subjective perception of reward value and probability. **Conclusions:** This simple test provides a robust measure of discriminative value thresholds and biases in decisions under risk. Prospect Theory makes predictions about choice patterns when perception of reward or probability is anomalous, as may occur in populations with dopaminergic or striatal dysfunction, such as Parkinson's disease and schizophrenia.

63.435 Reward-based Influences on Attentional Orienting in Patients with Visuo-spatial Neglect

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Recent evidence demonstrates that attentional allocation is sensitive to monetary reward (Kristjansson et al, 2005, 2010). What remains to be explored is the extent to which reward-based orienting influences attentional allocation. We examined whether visuo-spatial neglect, a deficit of attention to the left side of space, is sensitive to an imposed reward-based structure. Several studies suggest that a necessary component to improving attentional allocation in neglect is having a top-down goal (Snow & Mattingley, 2006). Therefore, the aim of the current study is to influence attentional allocation by biasing the neglected side with reward. Subjects completed a

pop-out search task in which one of three diamonds was a color singleton. The task was to report the location (top or bottom) of a missing notch on the singleton. One color was designated as the high reward stimulus, while the other was low reward. Color, and therefore reward level, could repeat or switch on every trial. Control participants exhibited effects of reward (faster reaction time for highly rewarded color) and of repetition (decreasing reaction time as the number of repetitions increased). In patients, with no reward structure, we found large differences in reaction time between the left and right sides, serving as the baseline level of neglect. To examine flexibility of attention, patients completed a color reward condition (same as controls) and a left side reward condition in which reward biased the left side of the display. The same RT differences were present with color reward, but decreased significantly in the left side reward condition indicating that attentional allocation was influenced by reward. The change in allocation of spatial attention indicates that reward can be used as a rehabilitative tool for neglect patients. These results provide strong evidence for the flexibility of attention and the possibility of plasticity and recovery after stroke.

Binocular vision: Stereopsis

Wednesday, May 11, 8:15 am - 12:15 pm

Orchid Ballroom, Poster Boards 436 - 447

63.436 Decoding disparity-defined surface curvature in the human brain

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Binocular disparity provides a powerful cue to depth structure that is important for both identifying and interacting with objects. Previous electrophysiological studies have located neurons tuned to disparity-defined surface curvature in both ventral (IT) and dorsal (IPS) processing pathways; however the cortical circuits mediating the perception of curvature in the human brain remain largely unknown. To test human cortical responses to curved 3D surfaces, we performed pattern classification analyses of human fMRI data obtained during stereoscopic presentation of random dot stereograms (RDS). Participants viewed RDS containing disparity-defined concave and convex hemi-cylindrical surfaces at two disparity magnitudes (± 6 and ± 12 arcmin). In addition, we presented control stimuli that were constructed by randomly shuffling the locations of disparities within the cylindrical stimuli. The fMRI data were used to train a support vector machine (SVM) classifier to predict the disparity sign (crossed vs. uncrossed) of stimuli based on activation in visual cortex. Comparing SVM classification accuracies for curved versus randomized stimuli indicated that intermediate regions of extrastriate cortex (especially V3A) encode information that is diagnostic of global 3D shape rather than just disparity content. Further, in dorsal visual areas (V3, V3B and V7) we observed increased classification accuracy with increased disparity magnitude for curved surfaces compared to randomized versions. In contrast, ventral area LO appeared insensitive to changes in the magnitude of convexity; specifically, the SVM's accuracy in predicting the categorical convexity sign (convex vs. concave) remained the same when disparity magnitude differed between training and test stimuli. These results support the proposal that dorsal areas respond to metric depth structure while ventral areas encode depth configurations.

63.437 The perception of 3D shape from binocular views of specular objects

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When viewing a specular object, such as a highly polished kettle, the retinal image consists of a distorted version of the surrounding environment. If viewed binocularly, a given environmental feature is generally reflected to the left and right eyes from different surface locations, leading to a pattern of disparities that does not coincide with the true physical location of the surface. Previous psychophysical work (Blake & Bülthoff, 1990, *Nature*, 343, 165) suggests that specular reflections can be used to constrain the 3D shape interpretation of partially-specular surfaces. However, here we ask how observers perceive 3D shape when viewing wholly-specular objects that give rise to complex patterns of disparity. In particular, we ask whether participants (a) recover the physical location of the surface or (b) perceive the surface location at the disparity-defined distance. First, we

report the results of mathematical simulations designed to quantify the disparity fields produced by viewing smooth 3D objects ("potatoes") binocularly. We develop a method for quantifying binocular disparities based on matching the reflected ray vectors for the two eyes, illustrate how specular surfaces give rise to complex, and often abrupt, changes in disparity, and discuss the matching ambiguities that are inherent when viewing specular objects. Second, we report the results of psychophysical experiments in which observers ($n=6$) used a disparity-probe method to indicate their perception of specular 3D shapes ($n=9$). Observers made multiple settings for a hexagonal grid of points ($n=61$) that overlaid the objects. We find that observers neither (a) recover the physical surface location nor (b) match disparities. Our mathematical simulations suggest that disparity signals are differentially reliable at different locations on an object's surface, suggesting that observers' settings may result from the propagation of depth estimates from reliable portions of the object.

63.438 Asymmetric transfer of perceptual learning between coarse and fine depth discriminations

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A prominent view in the literature posits that coarse and fine binocular disparities are processed by the dorsal and ventral pathways of the brain, respectively. However, neurophysiological data have shown that the contribution of dorsal areas to coarse depth discriminations can be altered through training on fine depth discriminations. Here, we use human psychophysics to investigate the perceptual learning of depth discriminations and test whether learning of fine depth discrimination alters performance on a coarse depth task, and vice versa. Observers were presented with random-dot stereograms depicting a central plane (target) within a background (surround) and judged whether the target was nearer or farther than the surround. Task difficulty was manipulated by (i) varying the percentage of signal dots (Coarse task), or (ii) the disparity difference between the target and the surround (Fine task). Half of the observers were trained on 840 trials with feedback on the Coarse task, the other half on the Fine task. All participants were tested on both tasks before and after training without feedback. The results show that training improves performance in the depth tasks, but not in an untrained, control (orientation discrimination) task. Importantly, we show that training on the Fine task leads to substantial improvements on the Coarse task, with participants improving by 70% of the total measured under dedicated training on the Coarse task. In contrast, when observers were trained on the Coarse task, we observed only 28% learning on the Fine task. These results demonstrate asymmetric transfer of learning between coarse and fine depth discriminations – a pattern that may reflect differences in the mechanisms recruited by the two tasks. We suggest that training on the fine task may enhance the representation of depth features, while training on the coarse task may enhance signal-to-noise processing, but have limited influence on feature representations.

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63.439 fMRI responses in higher dorsal areas relate to depth discrimination for both coarse and fine disparity tasks

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The cortical processing of coarse and fine binocular disparities is suggested to be specialised in the dorsal and ventral pathways respectively. Here we use human fMRI to test for patterns of brain activity that relate to performance on coarse and fine disparity tasks along the dorsal and ventral visual pathways. We used parametric stimulus variations to manipulate participants' performance in coarse and fine depth tasks and sought to identify cortical regions that contained information that varied in line with perceptual judgments. Participants viewed random-dot stereograms that contained a target plane with crossed (near) or uncrossed (far) horizontal disparity and judged its position (near or far) relative to the background. For the coarse task, we varied the proportion of dots located at the depth of the target plane (± 6 arcmin). In the fine task, we varied the relative disparity between the target plane and its surround. We measured event-related fMRI responses and used multi-voxel pattern classification methods to determine cortical regions that contained information about the disparity-defined depth. Correlating the performance of human observers with that of the classifier showed a close relationship between behavioural performance and fMRI brain patterns in dorsal regions for the coarse task (V3A,

V7, VIPS, POIPS). Interestingly, this result was also evident in higher dorsal regions for the fine task. However, we did not observe significant variations in classification performance in line with perceived depth for either task in regions of the ventral pathway. Our results suggest the important contribution of higher dorsal visual areas when making both coarse and fine depth judgments.

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63.440 Cortical areas involved in processing planar stereo motion

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Brain regions involved in processing planar stereoptically-defined motion (third-order motion) were investigated using fMRI. Visual stimuli that produced the perception of a depth-defined grating, translating in the fronto-parallel plane, were produced in a dynamic random dot stereogram (DRDS). DRDS stimuli contain no luminance or texture cues to motion, nor any monocular temporal or spatial information. Features for motion perception are available only through stereoptically combining the images in the two eyes. Method: In a Siemens 3T Trio system, we compared cortical BOLD activations generated by motion of the stereo-depth grating, depth-reversal-flicker of the stereo grating, and a stationary stereo grating to a flat stereo plane (the baseline). A block design was used to present the three stereo conditions (stereo motion, stereo flicker, and stationary stereo) interleaved with the baseline condition to six subjects. Separate functional localizer studies defined 13 cortical regions of interest (ROI). Results: V1 and V4 showed no activation differences to any stereo condition compared to zero-disparity baseline. The earliest areas activated by the stereo gratings were V2, V3, and V3a; these retinotopic areas did not differentiate the three stereo conditions. Dorsal intraparietal sulcus [DIPS], middle temporal and middle superior temporal cortex [MT, MST], inferior temporal sulcus [ITS] and cyclopean stereomotion area [CSM] showed significant activation to all stereo conditions with greatest activation for stereo motion. Precentral sulcus (PrCS) activated significantly only for stereo motion. Posterior superior temporal sulcus [STSp] and supramarginal gyrus [SMG] showed no difference in activation for stereo motion and flicker, but showed negative activation for stationary stereo relative to baseline, suggesting that these regions may suppress stationary patterns in favor of dynamic ones. Conclusion: The great diversity of brain activations for stereo-defined stimuli suggests that stereo information is extracted early and processed subsequently like other pattern and motion information.

63.441 Decoding da Vinci : quantitative depth from monocular occlusions

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Nakayama and Shimojo (1990) demonstrated that quantitative depth percepts could be generated by monocular occlusions, a phenomenon they called da Vinci stereopsis. They used a configuration where a monocular bar was placed to one side of a binocular rectangle. When an occlusion interpretation was possible, the bar appeared behind the rectangle at a distance that increased as the lateral separation between the bar and the rectangle increased. Gillam, Cook and Blackburn (2003) argued that quantitative depth perception in da Vinci stereopsis was due to double-matching of the bar with the edge of the rectangle. They showed that when the monocular bar was replaced with a monocular dot only qualitative depth percepts remained. However, their stimulus differed from the original in ways that promoted double-matching and the range of separations of the monocular feature from the rectangle was different for the bar and the dot. To evaluate the contributions of monocular occlusions and double-matching to quantitative depth percepts in da Vinci arrangements, we have replicated and extended the Nakayama and Shimojo and Gillam et al. experiments. We reproduced the original stimuli precisely and used the same range of separations for the bar stimuli as for the dot stimuli. We also compared perceived depth from disparity in the bar and dot stimuli when they were presented binocularly. Three of six observers were able to see quantitative depth with the dot stimulus though less depth was perceived than when a monocular bar was used. Interestingly, we found a similar difference in perceived depth when the bar and the dot were presented binocularly. Taken together our results provide evidence that quantitative depth in da

Vinci arrangements is based, at least in part, on monocular occlusions, and that this phenomenon depends on the properties of the monocular object and is subject to inter-observer differences.

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63.442 On the quantitative nature of depth percepts from fused and diplopic stimuli

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Introduction. Psychophysical and physiological studies of stereopsis have demonstrated the existence of luminance based (1st-order) and contrast-based (2nd-order) processing. The 2nd-order mechanism is thought to provide depth information when the luminance information is unreliable or unavailable. A number of investigators have suggested that 2nd-order stereopsis provides only qualitative depth information, but this proposal has not been tested empirically. The aim of this set of experiments is to evaluate this claim and in doing so clarify the contribution of 2nd-order processing to human depth perception.

Methodology. We have used a novel two-temporal alternative forced-choice procedure and a method of constant stimuli. This task was designed to avoid the separation confound inherent in discrimination tasks using diplopic stimuli. Observers were required to judge which of two intervals contained the largest difference in depth between a reference + disparity pedestal and a target + disparity pedestal. We assessed performance across a large range of fused and diplopic disparities, and measured diplopia for each observer. In addition we used stimuli designed to favour 1st-order, or isolate 2nd-order processing, to permit comparison of the relative contributions of these two mechanisms.

Results. All observers were able to perform the 2IFC depth interval judgment using both 1st and 2nd-order stimuli, though there were large and consistent differences between these conditions. The most notable result is that observers perceived quantitative depth from targets that isolated 2nd-order processing. Results from the 1st-order condition show a clear transition from high-resolution performance in the fused range to coarser low-resolution depth perception in the diplopic range, which is likely mediated by 2nd-order processing. This study provides the first definitive evidence that quantitative depth can be provided by both 1st- and 2nd-order mechanisms in the fused range, but only the 2nd-order signal is used when stimuli are diplopic.

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63.443 Stereoscopic adaptation to relative perceived slant

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Studies of stereo slant adaptation have generally concluded that the slant after-effect (SAE) results from adaptation to perceived slant rather than to disparity gradients, with greater adaptation to greater perceived slant. Here we report a contrary example. We compared the SAE for a single slanted surface, as conventionally used, with adaptation to a surface with relative as well as absolute slant information. Despite measurably increasing perceived slant, the addition of relative slant much reduced the SAE. In Experiment 1, a central random dot surface (5.2°H x 7.8°W) was magnified horizontally (4%) in one eye consistent with slant around the V-axis. Frontal plane surfaces (2.6°H x 7.8°W), when present, flanked the central surface at a separation of 0.5 deg vertically. Observers fixated within a central area of the slanted central surface with or without the flanking surfaces for one minute. Then the SAE was measured by nulling the apparent slant of the central surface using a staircase procedure. The flanking surfaces were present/absent at test. The SAE was found to be significantly lower for the relative slant condition. Additionally, the presence of relative slant for the test stimulus much reduced the SAE even following adaptation to a single slanted surface. In Experiment 2 relative slant at adaptation or test likewise reduced the SAE when the central surface was slanted around the H-axis and was flanked horizontally by frontal plane surfaces. The results indicate that the SAE found for single slanted surfaces is not mainly due to adaptation of perceived slant, but in large measure due to slant normalisation, which is much reduced under conditions of relative slant at adaptation or test. The results are also inconsistent with the view that the SAE is principally due to the adaptation of disparity gradient detectors, which would still operate under conditions of relative slant.

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63.444 Non-transitive Depth in Stereo Displays

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We have developed stimuli whose perceived relative depth is unrelated to horizontal disparity parameters. For these stimuli, knowing that the horizontal component of disparity is positive for one stimulus and negative for another is insufficient for predicting their perceived depth order (VR, 2009, p. 2209). The only non-standard feature of these stimuli—a grating and a plaid—is the oblique disparity direction of the plaid.

With these stimuli one can create non-transitive depth relations: Stimulus A is seen as farther than Stimulus B when they are presented together; Stimulus B is seen as farther than Stimulus C when they are presented together; but A is not seen as farther than C, but rather at the same depth or even nearer. Here we ask, What depths are seen when A, B, and C are all presented together?

In Experiment 1, observers attended to all three stimuli (one grating, two plaids) of A+B+C displays and selected both the nearest and the farthest stimuli. Grating disparity affected observers' judgments, making two plaids with equal horizontal disparities appear at different depths, a perceptual depth shearing that resolves the pairwise non-transitivity.

In Experiment 2, we examined the effect of an unattended stimulus on observers' depth judgments of the two task-relevant stimuli. With practice some but not all observers could use selective attention to modulate the perceived depth of some relevant stimulus pairs. However, observers were unable to eliminate the effect of an unattended grating. The grating again made plaids with equal horizontal disparities appear at unequal depths.

The results demonstrate a non-local disparity field affecting perceived stereo depth and subject to only limited attentional selectivity.

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63.445 Illusory "Neon" Spreading of Perceived Depth Implies an Anisotropic Propagation Constraint in Depth Reconstruction

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A striking illusion of the color propagation, termed "Neon Color Spreading" was described by Varin (1971) and van Tuijl (1975). A display of thin rectangular spokes emanating radially from a central point, where the inner half of each spoke is red while the outer half is black, generates the vivid percept of the red color spreading to form a filled in red disc (radius the length of the red portion of the spokes). We wondered if there is an analogous effect for depth from binocular disparity. Corresponding to the color spreading displays, we made binocular displays consisting of thin rectangular spokes on a white background emanating radially from a central point. The spokes were made of random closely-spaced black dots. The disparity of the inner 1/3 of each spoke was set to give them the appearance of far depth (or of a depth slant through the plane of the screen), while the remaining spoke lengths had zero disparity so as to appear in the plane of the screen. Upon fusing the binocular stimuli, the perceived depth of the inner spokes spread so that the white space of entire inner disc region appeared to be displaced in depth (or as a disk slanted in depth), with a sharp border between the disk and the plane of the screen. Detailed depth-matching measurements across the sharp border perceived in the white inter-spoke region quantified the abrupt depth jump in the absence of local disparity cues. We conclude that perceived depth not only participates in the spreading phenomenon corresponding to the color effect but can propagate along sharp edges for long distances from the defining disparity information. This observation challenges classic models of depth propagation according to an isotropic smoothness constraint and suggests the need for strong anisotropic propagation in depth reconstruction models.

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63.446 Stereo improves 3D shape discrimination even when rich monocular shape cues are available

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Stereo is a powerful 3D cue, but there is mixed evidence about whether stereo contributes to recognizing objects across changes in viewpoint. Some previous studies have demonstrated a stereo advantage for recognition of unfamiliar objects across viewpoints. However, in these studies, 3D structure was not well-specified by monocular information (e.g. bent paperclips).

When rich monocular cues to 3D shape are available, does stereo still provide a benefit? We tested shape discrimination for smoothly-curved, solid random shapes in three viewing conditions: shading-only, stereo-only, and combined shading and stereo. Objects were simulated to have a fine homogeneous surface texture, and illumination was either ambient (stereo-only) or a diffused point light source (shading-only and combined conditions). A mirror haploscope was used to present binocular images. Observers performed same-different shape discrimination judgments for sequentially presented images. Standard and test objects were either the same orientation or differed by a rotation in depth of $\pm 15^\circ$, $\pm 30^\circ$, or $\pm 60^\circ$ around the vertical axis. To discourage a 2D strategy, pairs of comparison shapes were constructed to have the same occlusion contour when viewed from the base orientation, and light source direction was varied between standard and test objects. We found that rotation in depth markedly impaired discrimination performance in all viewing conditions, as evidenced by reduced sensitivity (d') and increased bias toward judging same shapes as different. We also observed a consistent benefit from stereo for all viewpoint conditions. Although the shading-only images produce a strong subjective percept of 3D shape, observers were not able to reliably discriminate shapes across changes in viewpoint (30° : $d' = .86$, 60° : $d' = .46$). Discrimination was significantly better with binocular viewing (30° : $d' = 1.34$, 60° : $d' = .78$). Our results demonstrate that shape perception for random 3D objects is highly viewpoint-dependent, and that stereo information can reduce viewpoint costs.

63.447 Solving the correspondence problem between two views using a priori constraints

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When a 3D scene is viewed with two eyes (or with one eye before and after head translation), 3D features in the scene are projected to different positions on the retinas. This difference is called binocular or motion parallax. Before the parallax is used to solve 3D shape and scene recovery problems, the correspondence between pairs of the projected features of the same 3D points in the two retinal images must be established. Our everyday life experience suggests that the correspondence problem is almost always solved by our visual system quickly and correctly. This observation contrasts with computational difficulty of the problem: there are very many features in real 3D scenes, and a brute force search for correct correspondences in the retinal images will lead to a combinatorial explosion. As in every ill-posed inverse problem, a priori constraints are required. We propose a computational model that solves the correspondence problem using a constraint that objects in the scene, as well as the observer (robot) are resting on a common horizontal floor. The robot acquires images from its two cameras, whose lines of sight are parallel. The robot knows its own height, and the orientation of its cameras relative to gravity is measured by an inclinometer (the inclinometer's accuracy is similar to the accuracy of the human vestibular system). We show that the left image of the floor is a shear transformation of the right image. This makes the correspondence problem for the floor texture trivial. The same transformation applies to the bottom parts of the objects resting on the floor. Finally, the correspondences of the remaining features of the objects are established by proceeding from the bottom parts of the objects towards their top. We will show results of the robot's performance with pairs of images of real scenes.

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Development: Lifespan and aging

Wednesday, May 11, 8:15 am - 12:15 pm
Orchid Ballroom, Poster Boards 448 - 458

63.448 Effects of Normal Aging on Suprathreshold Contrast Perception

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Thresholds for a number of visual capacities (motion, contrast, orientation) show significant age-related elevations. We assessed suprathreshold contrast perception across the lifespan. A total of 93 healthy subjects (16-74 years) participated. In Experiment 1 subjects adjusted the contrast of a matching grating (0.50 or 2.0 x 4.0; 0.075 c/d) to equal that of both real (30% contrast, 0.075 c/d) and induced (Mccourt, 1982) test gratings (100% induc-

ing grating contrast; 0.075 c/d). Matching gratings appeared in the upper visual field and test gratings appeared in the lower visual field (eccentricity $\pm 7.5^\circ$) or vice versa. For test gratings situated in the upper visual field matching contrast increased with age, whereas the opposite occurred for test gratings situated in the lower visual field, indicating a significant age-related reduction in perceived suprathreshold contrast for stimuli in the lower visual field. Regression analyses show significant age-related reductions in perceived grating contrast in the lower versus upper visual field for both real and induced gratings [Real (20): $F(92)=24.67$, $p<0.001$; Induced (0.5°): $F(92)=20.94$, $p<0.001$; Induced (2°): $F(92)=11.65$, $p<0.001$]. In Experiment 2 a quadrature-phase motion technique (Blakeslee & McCourt, 2008) was used to measure canceling contrast (in foveal viewing) for induced gratings at two temporal frequencies (1 and 4 Hz) at two test field heights (0.5° and 2°). Regression analyses show a significant age-related reduction in canceling contrast at 4 Hz [0.5° test field: $F(92)=14.51$, $p<0.001$; 2° test field, $F(92)=7.23$, $p<0.001$], but not at 1 Hz [0.5° test field: $F(92)=0.09$, $p=0.761$; 2° test field, $F(92)=0.50$, $p=0.477$]. These results are consistent with previous reports that age-related visual changes are largest at higher temporal frequencies, and are the first to disclose significant differential age-related changes in suprathreshold vision between the upper and lower visual fields.

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63.449 Increased spatial surround suppression in the elderly

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Betts et al. (2005) showed that older observers needed shorter stimulus presentation times than younger adults to determine the motion direction of a large drifting Gabor. This was explained by a reduction in surround suppression in older observers, possibly due to a reduction of cortical inhibition. However, we measured increased surround suppression in older adults using a centre-surround contrast task (Karas and McKendrick, 2009). The magnitude of surround suppression depends on the stimulus parameters of the centre and surround. Here we use a series of stimulus parameters to explore the generality of our finding of increased contrast-contrast suppression in the elderly. Fifteen younger (18-33 years) and 18 older (61-84 years) adults participated. Using a method of constant stimuli, perceived contrast was measured for a sine wave grating (0.67 deg, 4c/deg) with and without an annular surround (4 deg, 4c/deg). The following parameters were varied: a) contrast polarity of centre and surround (70%/40% contrast in centre-surround); b) border in phase and out of phase (180 deg); c) reduced contrast for younger observers (to match saliency to older observers). A second experiment (10 younger and 10 older participants) explored the addition of drift to the grating stimulus (2c/deg, 2 deg/sec). The shift in point of subjective equality (PSE) was measured for each condition. Older participants showed a greater shift in PSE (greater surround suppression) for each condition: lower surround contrast, both in and out of phase [$F(1, 31) = 17.4$, $p<0.001$]; matched contrast saliency [$F(1,31)=19.8$, $p<0.001$]; and drifting gratings [$t(18)=5.9$, $p<0.001$]. For the range of parameters tested, on average older participants demonstrated an increase in surround suppression. Our study demonstrates a robust effect of increased contrast-contrast surround suppression in the elderly for a wide range of stimulus parameters.

Acknowledgement: ARC DP0877923, ARC FT0990930

63.450 The effects of aging on low and intermediate stages of form processing

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This study explored the effects of healthy aging on the early stages of the processing of contours and shapes. Forty-two adults participated. Participants were divided into three groups: 16 young adults (19 to 34 years, mean = 27); 12 middle aged adults (40 to 59 years, mean = 50); and 14 older adults (63 to 73 years, mean = 66). Four visual tasks were employed: 1) collinear facilitation for 3 c/deg Gabor patches; 2) contrast-contrast spatial surround suppression (Chubb illusion) where contrast matching thresholds were measured for a 40% contrast, 4 c/deg sinusoidal grating circular patch (0.67 deg radius) in the presence and absence of a 95% contrast grating annulus (4 deg radius); 3) a contour integration task involving discriminating an elliptical global contour from a circular contour in noise; and 4) Glass pattern coherence thresholds. Compared to young adults, the older group showed: a reduced strength of collinear facilitation ($p<0.05$); an increased magnitude of surround suppression for the centre-surround task ($p<0.05$);

elevated aspect ratio thresholds for the detection of the elliptical contour in noise ($p < 0.05$); and elevated Glass pattern coherence thresholds ($p < 0.05$). There was also a trend for older observers to require closer spacing between contour elements within the contour integration task ($p = 0.07$). Mean thresholds for the middle aged adults fell between those of the younger and older groups for all tasks. Effect sizes (Cohen's d) were calculated to compare the aging effects between tasks: collinear facilitation: 0.8; surround suppression: 1.9; global contour integration: 0.8; Glass pattern coherence thresholds: 0.9. Overall, the results show that normal aging alters performance for a range of low through intermediate form processing tasks, with the largest effect being a substantial increase in the suppression of apparent contrast by the presence of a high-contrast annular surround.

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63.451 Aging and Stereoscopic Shape Discrimination

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Twenty older (mean age was 70.6 years) and younger observers (mean age was 23.1 years) participated in a study designed to investigate stereoscopic shape discrimination. The stereoscopic surfaces (approximately 24.6 minutes peak-to-trough binocular disparity) to be discriminated all had sinusoidal depth modulations, where the resulting peaks and troughs formed concentric circles, were radially-oriented, or were arranged like an "egg-crate" (i.e., binocular disparity = $\sin(x) * \sin(y)$). The visibility of the stereoscopic surfaces was degraded to varying degrees by embedding the surfaces in volumetric "noise" (e.g., 50 percent of the stereoscopic points were located on a smooth 3-D surface, whereas the remaining 50 percent of the points occupied random locations in a cubical volume surrounding the depicted surface). While the discriminability of all observers was adversely affected by the presence and magnitude of the volumetric noise, the older observers' performance suffered more (e.g., the younger observers' performance was 30 percent higher than that of the older observers when 40 percent of the stereoscopic points defined a smooth surface and 60 percent of the points comprised noise). The performance of all observers was facilitated when the random-dot stereograms were dynamic (updated at 35 Hz) instead of static. However, the improvement in performance for dynamic stereograms was larger for the younger observers and smaller for the older observers. The results demonstrate that while older adults generally possess good stereopsis, their shape discrimination performance is not as robust or accurate as that of younger observers, especially when stereoscopic surfaces are degraded by volumetric noise.

63.452 The correspondence problem in apparent motion perception and aging

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The largest spatial displacement of dots in a two-frame random-dot kinematogram yielding good direction discrimination performance (i.e., D_{max}) is reduced in older observers (Roudaia et al., J. Vis., 2010). D_{max} depends on dot density, which suggests that D_{max} is constrained by the number of false targets in the display (Eagle & Rogers, Vis. Res., 1997). As such, the reduction in D_{max} with aging may be caused by an age-related decline in the efficiency of solving the correspondence problem. The current study investigates that hypothesis. Stimuli consisted of white dots (0.04×0.04 deg) randomly distributed in a small, medium, or large square patch (height: 6.4, 12.7, or 25.4 deg) on a black background. The number of dots was varied to yield average density levels ranging from 0.025% to 5%. On each trial, two random-dot patterns were presented for 100 ms each, separated by a blank ISI lasting 40 ms. The second pattern was identical to the first pattern, but was shifted within a display window to the right or to the left by a displacement ranging from 0.03 to 5.6 deg. Direction discrimination accuracy of older (mean age: 74 years) and younger (mean age: 24 years) subjects was measured in 105 conditions blocked by patch size. Performance in both groups was best at medium displacements, and declined at smaller and larger displacements. Decreasing density did not affect performance at short displacements, but improved performance at large displacements. Importantly, this improvement was significantly greater in older than younger subjects, such that the effect of age at large displacements greatly

reduced with decreasing density. These results support the hypothesis that age-related declines in performance at large displacements are caused by a reduced ability to solve the correspondence problem in motion.

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63.453 The effect of aging on directional tuning when making judgments about horizontal and vertical motion

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Motion direction identification is impaired in older subjects (Bennett et al., Vis Res, 2007). One explanation for this effect is that the bandwidth of directionally selective mechanisms broadens with age. Although neurophysiological work with senescent primates has found evidence of broader directional tuning in V1 neurons, it is not known if directional tuning changes similarly as a function of age in human observers. To investigate this issue, we measured direction discrimination thresholds in six younger and six older adults. The stimuli were random dot kinematograms (RDK; 400 dots), and the dependent variable was the percentage of coherently moving dots needed to discriminate left-right or up-down motion. RDKs were embedded in a mask consisting of 100 dots moving coherently in four directions: $d \pm \theta$ deg and $(d+180) \pm \theta$ deg, where d is the target direction and θ is the difference between target and mask directions. For both left-right and up-down target motion, thresholds in both age groups declined monotonically as θ increased from 5 to 90 deg. For left-right target motion, neither the slope of the masking function nor threshold in a no-mask baseline condition differed between age groups. For up-down target motion, the masking function obtained with older subjects had a slope that was one-half of the slope obtained with younger subjects, and threshold in the no-mask condition was, on average, twice as high in older than younger subjects. These preliminary results are inconsistent with the idea that there is a non-specific decrease in the selectivity of directionally-tuned mechanisms with age. They suggest, instead, that the effect of aging on the selectivity of directional masking may vary with the target direction. Currently we are replicating this result on a larger sample of subjects, and generalizing it to different dot densities and speeds.

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63.454 Effects of development on low-level feature processing during natural viewing of dynamic scenes

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Eye movements have been widely used to examine many aspects of brain functions, such as reflexive response, inhibitory controls, and working memory, in normal development. However, it is unclear how normal development affects eye movements of natural viewing behavior. This study specifically examined the developmental trajectory of low-level features processing while participants freely viewed videos of natural scenes. These videos are composed of short (2-4 seconds), unrelated clips. This design was to reduce top-down expectation and to magnify the difference in gaze allocation at every scene change. Gazes of 3 groups of participants (18 children, 10.7 ± 1.8 yr; 18 young adults, 23.2 ± 2.6 yr; 24 elderly, 70.3 ± 7.5 yr) were tracked while they watched the videos for 20 minutes. First, we used a computational saliency model (Itti & Koch, 2001) to compute bottom-up saliency maps for each video frame. These saliency maps can be computed from a single feature (e.g. color contrast, motion contrast) or a combination of them. Next, we computed the correlation between saliency and gaze of each population. To reveal the developmental trajectory of low-level features processing, classifiers were built to differentiate (1) children vs. young adults, and (2) young adults vs. elderly. In the mean time, a feature selection method was performed to identify the most discriminative features for differentiating the populations. Using this method, we found that during normal maturation (children to young adults), there was a reduction in saccade interval and an increase in correlation between gaze and texture contrast, orientated edges, and color contrast. On the other hand, during normal aging (young adults to elderly), we found an increase in saccade interval and a decrease in correlation between gaze and oriented

edges. In conclusion, this study revealed for the first time the differences between age groups in low-level feature processing during natural viewing of dynamic scenes.

63.455 Age-related decline in reading abilities revealed by a positional character noise paradigm

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Aging is associated with a decline in a number of cognitive functions. Healthy elderly adults, however, are able to read words of large character size as fast as young adults (Akutsu, Legge, Ross & Schuebel. *J Gerontol.*, 1991). We used a novel paradigm to study the ability of the elderly and young to read words embedded in positional noise. The speed for reading unrelated words in the presence of random vertical displacement of character position was measured in young (n=20, mean age=23years) and older observers (n=20, mean age=73). Both groups had normal visual acuity and MMSE scores. Vertical character positions were sampled from a Gaussian distribution with variance in the range 0-60% of the character height. Observers were presented with samples (10 lines, 8 words/line of 3, 4, 5 and 6 characters; Courier monospaced font) of dark words on white background of 135 cd/m² mean luminance. Normal, reversed and phonetically irregular words were used with font size 12 (21.5 min of arc) and contrast of 96%. Positional noise produced a significant decline in reading speed for normal and phonetically irregular words. For these words, both groups did not show significant differences in reading speed without positional noise. In the presence of positional noise older readers showed a significantly stronger decline than young readers for normal words, but not for phonetically irregular words. Reading speed for reversed words did not depend on positional noise although the older group was 30% slower than young group. The reading-speed decline with increasing positional noise level in the elderly for normal words suggests age-related deficits in noise extraction. These deficits were not found when processing phonological word information. The lack of noise effect on reading speed for reversed words may result from their noisy neural representations and slower mental processing.

63.456 Age related differences in the spatial extent of attention in 3D space

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Usually visual spatial attention is measured using two-dimensional (2D) stimuli with the implicit assumption that the scope of 2D spatial attention has a direct relationship to the extent and shape of three-dimensional (3D) spatial attention. However, several experiments have demonstrated that spatial attention varies as a function of distance (e.g. Andersen, 1990; Andersen & Kramer, 1993; Ferlazzo et al., 2008; Maringelli, et al., 2001). Similar results have been found for older observers (Atchley & Kramer, 1998). In addition, the efficiency with which 2D spatial attention shifts occur in older adults may be equivalent to younger observers (Folk & Hoyer, 1992). However, the useful field of view (UFOV; Sekuler & Ball, 1986), a measure of 2D spatial attention, provides evidence that the scope of 2D visual attention is reduced in older adults. The current experiment was designed to assess whether 3D spatial attention differs as a function of age and how task difficulty changed the extent of attention. Specifically, we used a driving scenario to examine 3D attention by requiring participants' to detect a light-change target in an array of lights over a simulated roadway while they performed a car following task. We found that reaction time to light-change targets varied as a function of distance and horizontal position in younger adults, but only as a function of distance in older adults. As a result, reaction time for older observers did not vary as a function of horizontal position at the greatest distance examined. These results indicate the shape of spatial attention in the horizontal and depth dimensions is different for older and younger observers.

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63.457 Changes in perceptual-motor learning across the lifespan: 20, 60, 70, and 80 year olds

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Introduction: Many perceptual-motor tasks require rhythmic movements of limbs, pendulums, or display stimuli, with specific relative timing. People can generally only produce two stable coordination patterns without training: 00 and 1800. Others (e.g. 900) usually have to be learned. Surprisingly, there are no major studies of rhythmic coordination learning across the lifespan. As part of a larger study, here we compare the learning of younger (20 years) and older (60, 70, 80 years) adults. Method: We presented two vertically displaced white dots against a black background. The computer controlled the top dot and the participant controlled the bottom dot via a joystick. Sessions involved the target phase relationship being displayed before participants attempted to produce the same coordinative pattern. There were three assessment sessions (Baseline, Post-training, Retention x 4 trials = 12 total) with 00, 1800 and 900, and five training sessions (10 trials) with only 900. Feedback was provided in training by changing the person-controlled dot from white to green when the participant was moving at 900± an error band that decreased as performance improved. Results: All groups improved significantly across training and this was generally retained post-training. Nonetheless, learning rates were different between groups and decreased with age, with the older adults also showing highly variable performance. The introduction of feedback immediately improved performance in the young but not older adults. Discussion: The older adults showed reduced learning rates although the age of steepest decline has yet to be determined. The immediate improvement of the young with the introduction of the green dot implies the feedback usefully constrained the state space and thus allowed them to become attuned to the relevant perceptual variables - and therefore learn rapidly. In contrast, feedback was less useful for the older participants suggesting the state space remained relatively unconstrained with the negative consequences reflected in the learning rates.

63.458 Don't look here! The relationship between eye movement artifacts, covert attention, and visual working memory in older adults

Kristin E. Wilson¹(kristin.wilson@utoronto.ca), Stephen M. Emrich¹, Megumi Noda¹, Vince Brienza¹, Susanne Ferber¹; ¹Department of Psychology, University of Toronto

The Inhibition Theory of aging suggests that age-related decline in cognition results from a deficit in top-down inhibitory control, a process critical to efficient and effective use of capacity-limited resources, such as visual working memory (VWM). Evidence supporting this theory can be found in studies of overt attentional control (anti-saccades) and VWM. Covertly shifting attention - inhibiting eye movements while moving attention - is a requirement in many EEG studies, due to the artifacts/noise associated with eye-movements. Thus, this skill becomes an implicit data selection criterion, resulting in the exclusion of participants that are simply unable to control their eye movements. This may pose a significant problem when studying older adults. We investigated the relationship between VWM capacity (k) in older and younger adults and the ability to suppress eye-movements during a Localized Attentional Interference (LAI) task, while EEG was recorded. Eye movements were tracked using electrodes placed above, below and at the outer canthi of each eye. Participants were presented with a search array, containing a single coloured target (T) and distractor (L) among gray place-holders, positioned on an invisible circle, centered around a fixation cross. Despite saccade inhibition training, a number of older adults were unable to inhibit their eye movements. Interestingly, their mean k-estimate was significantly lower than the k-estimate of those elderly participants who could inhibit eye movements. Furthermore, a significant negative correlation was found between percent of trials contaminated by saccades and VWM capacity, but only for the older adults. These results suggest that excluding older adult data sets due to excessive eye movement artifacts may result in systematically rejecting lower performing older adults, misconstruing age-related changes in electrophysiology.

Acknowledgement: Canadian Institute of Health Research (CIHR)

Topic Index

Below is a list of talk and poster sessions by topic. Parentheses indicate the abstracts that are included in each session.

- 3D perception
Oral Presentation (51.11-51.17)
Tuesday, May 10, 8:00 - 9:45 am
- 3D perception: Contours, shading and texture
Poster Presentation (23.413-23.423)
Saturday, May 7, 8:15 am - 12:15 pm
- 3D perception: Dynamic cues
Poster Presentation (33.532-33.538)
Sunday, May 8, 8:15 am - 12:15 pm
- 3D perception: Natural and virtual scenes
Poster Presentation (56.419-56.434)
Tuesday, May 10, 3:00 - 7:00 pm
- Attention: Capture
Poster Presentation (33.501-33.516)
Sunday, May 8, 8:15 am - 12:15 pm
- Attention: Divided
Poster Presentation (56.549-56.558)
Tuesday, May 10, 3:00 - 7:00 pm
- Attention: Emotion
Poster Presentation (63.423-63.430)
Wednesday, May 11, 8:15 am - 12:15 pm
- Attention: Endogenous and exogenous
Poster Presentation (26.420-26.432)
Saturday, May 7, 2:45 - 6:30 pm
- Attention: Features and objects
Oral Presentation (21.21-21.27)
Saturday, May 7, 8:00 - 9:45 am
- Attention: Features and objects
Poster Presentation (26.433-26.453)
Saturday, May 7, 2:45 - 6:30 pm
- Attention: Inattention and attention blindness
Poster Presentation (16.518-16.525)
Friday, May 6, 6:45 - 9:30 pm
- Attention: Models
Poster Presentation (36.452-36.457)
Sunday, May 8, 2:45 - 6:30 pm
- Attention: Neural mechanisms II
Poster Presentation (36.436-36.451)
Sunday, May 8, 2:45 - 6:30 pm
- Attention: Neural mechanisms and reward
Oral Presentation (32.21-32.27)
Sunday, May 8, 10:45 - 12:30 pm
- Attention: Neural mechanisms I
Poster Presentation (16.501-16.517)
Friday, May 6, 6:45 - 9:30 pm
- Attention: Reward
Poster Presentation (63.431-63.435)
Wednesday, May 11, 8:15 am - 12:15 pm
- Attention: Shifting
Poster Presentation (53.420-53.428)
Tuesday, May 10, 8:15 am - 12:15 pm
- Attention: Spatial selection and modulation
Poster Presentation (53.301-53.329)
Tuesday, May 10, 8:15 am - 12:15 pm
- Attention: Spatial selection and modulation
Oral Presentation (41.21-41.27)
Monday, May 9, 8:00 - 9:45 am
- Attention: Temporal
Poster Presentation (43.319-43.329)
Monday, May 9, 8:15 am - 12:15 pm
- Attention: Temporal and capture
Oral Presentation (54.21-54.28)
Tuesday, May 10, 2:30 - 4:30 pm
- Attention: Tracking
Poster Presentation (23.424-23.441)
Saturday, May 7, 8:15 am - 12:15 pm
- Binocular vision
Oral Presentation (52.11-52.17)
Tuesday, May 10, 10:45 - 12:30 pm
- Binocular vision: Binocular combination and rivalry
Poster Presentation (23.401-23.412)
Saturday, May 7, 8:15 am - 12:15 pm
- Binocular vision: Binocular rivalry and awareness
Poster Presentation (36.318-36.328)
Sunday, May 8, 2:45 - 6:30 pm
- Binocular vision: Eye movements
Poster Presentation (43.417-43.425)
Monday, May 9, 8:15 am - 12:15 pm
- Binocular vision: Stereopsis
Poster Presentation (63.436-63.447)
Wednesday, May 11, 8:15 am - 12:15 pm
- Color and light: Adaptation and constancy
Poster Presentation (26.301-26.320)
Saturday, May 7, 2:45 - 6:30 pm
- Color and light: Lightness and brightness
Poster Presentation (16.526-16.536)
Friday, May 6, 6:45 - 9:30 pm
- Color and light: Mechanisms
Oral Presentation (42.11-42.17)
Monday, May 9, 10:45 - 12:30 pm
- Color and light: Memory, language and synesthesia
Poster Presentation (36.301-36.317)
Sunday, May 8, 2:45 - 6:30 pm
- Color and light: Surfaces and materials
Oral Presentation (21.11-21.17)
Saturday, May 7, 8:00 - 9:45 am
- Development: Amblyopia
Poster Presentation (33.324-33.332)
Sunday, May 8, 8:15 am - 12:15 pm
- Development: Childhood and infancy
Poster Presentation (33.311-33.323)
Sunday, May 8, 8:15 am - 12:15 pm
- Development: Disorders
Oral Presentation (41.11-41.17)
Monday, May 9, 8:00 - 9:45 am
- Development: Disorders
Poster Presentation (56.501-56.511)
Tuesday, May 10, 3:00 - 7:00 pm
- Development: Face perception
Poster Presentation (56.317-56.330)
Tuesday, May 10, 3:00 - 7:00 pm
- Development: Infancy and childhood
Oral Presentation (24.11-24.17)
Saturday, May 7, 2:30 - 4:15 pm
- Development: Lifespan and aging
Poster Presentation (63.448-63.458)
Wednesday, May 11, 8:15 am - 12:15 pm
- Eye movements: Cognition and scenes
Poster Presentation (16.401-16.422)
Friday, May 6, 6:45 - 9:30 pm
- Eye Movements: Mechanisms, methods and models
Oral Presentation (51.21-51.27)
Tuesday, May 10, 8:00 - 9:45 am
- Eye movements: Methods and gaze
Poster Presentation (43.401-43.416)
Monday, May 9, 8:15 am - 12:15 pm
- Eye movements: Perisaccadic perception
Poster Presentation (33.301-33.310)
Sunday, May 8, 8:15 am - 12:15 pm
- Eye movements: Pursuit and following
Poster Presentation (36.529-36.539)
Sunday, May 8, 2:45 - 6:30 pm
- Eye movements: Remapping
Oral Presentation (24.21-24.27)
Saturday, May 7, 2:30 - 4:15 pm

- Eye movements: Saccades and fixations
Poster Presentation (23.301-23.320)
Saturday, May 7, 8:15 am - 12:15 pm
- Face perception: Cognitive factors
Oral Presentation (52.21-52.27)
Tuesday, May 10, 10:45 - 12:30 pm
- Face perception: Disorders
Poster Presentation (23.534-23.545)
Saturday, May 7, 8:15 am - 12:15 pm
- Face perception: Experience and learning
Poster Presentation (33.411-33.427)
Sunday, May 8, 8:15 am - 12:15 pm
- Face perception: Expression and emotion
Poster Presentation (33.401-33.410)
Sunday, May 8, 8:15 am - 12:15 pm
- Face perception: Features and configuration
Poster Presentation (43.426-43.439)
Monday, May 9, 8:15 am - 12:15 pm
- Face perception: High-level features
Poster Presentation (56.301-56.316)
Tuesday, May 10, 3:00 - 7:00 pm
- Face perception: Neural mechanisms
Oral Presentation (35.21-35.26)
Sunday, May 8, 5:15 - 6:45 pm
- Face perception: Neural mechanisms
Poster Presentation (43.440-43.455)
Monday, May 9, 8:15 am - 12:15 pm
- Face perception: Parts and wholes
Oral Presentation (61.21-61.27)
Wednesday, May 11, 8:00 - 9:45 am
- Face perception: Wholes and parts
Poster Presentation (23.519-23.533)
Saturday, May 7, 8:15 am - 12:15 pm
- Motion: Biological motion
Poster Presentation (23.501-23.518)
Saturday, May 7, 8:15 am - 12:15 pm
- Motion: Encoding and aftereffects
Oral Presentation (31.11-31.17)
Sunday, May 8, 8:00 - 9:45 am
- Motion: Flow, depth, and spin
Poster Presentation (33.517-33.531)
Sunday, May 8, 8:15 am - 12:15 pm
- Motion: Higher-order, objects, and illusions
Poster Presentation (63.301-63.317)
Wednesday, May 11, 8:15 am - 12:15 pm
- Motion: Integration
Oral Presentation (55.21-55.27)
Tuesday, May 10, 5:30 - 7:15 pm
- Motion: Local mechanisms and models
Poster Presentation (36.540-36.556)
Sunday, May 8, 2:45 - 6:30 pm
- Motion: Neural mechanisms
Poster Presentation (26.509-26.520)
Saturday, May 7, 2:45 - 6:30 pm
- Multisensory processing
Oral Presentation (32.11-32.17)
Sunday, May 8, 10:45 - 12:30 pm
- Multisensory processing: Visual, tactile and vestibular interactions
Poster Presentation (26.321-26.333)
Saturday, May 7, 2:45 - 6:30 pm
- Multisensory processing: Visual-auditory interactions
Poster Presentation (36.422-36.435)
Sunday, May 8, 2:45 - 6:30 pm
- Noise and uncertainty
Poster Presentation (26.501-26.508)
Saturday, May 7, 2:45 - 6:30 pm
- Object recognition and scene perception: Neural mechanisms
Oral Presentation (62.11-62.17)
Wednesday, May 11, 10:45 - 12:30 pm
- Object recognition: Categories
Poster Presentation (56.512-56.529)
Tuesday, May 10, 3:00 - 7:00 pm
- Object recognition: Experience and learning
Poster Presentation (53.522-53.533)
Tuesday, May 10, 8:15 am - 12:15 pm
- Object recognition: Features
Oral Presentation (31.21-31.27)
Sunday, May 8, 8:00 - 9:45 am
- Object recognition: Features
Poster Presentation (56.530-56.548)
Tuesday, May 10, 3:00 - 7:00 pm
- Object recognition: Neural mechanisms
Poster Presentation (16.423-16.440)
Friday, May 6, 6:45 - 9:30 pm
- Object recognition: Parts and categories
Oral Presentation (25.21-25.26)
Saturday, May 7, 5:15 - 6:45 pm
- Perception and action: Locomotion
Poster Presentation (53.501-53.521)
Tuesday, May 10, 8:15 am - 12:15 pm
- Perception and action: Navigation and locomotion
Oral Presentation (25.11-25.16)
Saturday, May 7, 5:15 - 6:45 pm
- Perception and action: Navigation and wayfinding
Poster Presentation (36.401-36.412)
Sunday, May 8, 2:45 - 6:30 pm
- Perception and action: Neural Mechanisms
Poster Presentation (36.413-36.421)
Sunday, May 8, 2:45 - 6:30 pm
- Perception and action: Pointing and hitting
Poster Presentation (23.546-23.554)
Saturday, May 7, 8:15 am - 12:15 pm
- Perception and action: Pointing, hitting, reaching, and grasping
Oral Presentation (55.11-55.17)
Tuesday, May 10, 5:30 - 7:15 pm
- Perception and action: Reaching and grasping
Poster Presentation (33.428-33.444)
Sunday, May 8, 8:15 am - 12:15 pm
- Perceptual learning: Models
Poster Presentation (36.501-36.513)
Sunday, May 8, 2:45 - 6:30 pm
- Perceptual learning: Models and neural mechanisms
Oral Presentation (42.21-42.27)
Monday, May 9, 10:45 - 12:30 pm
- Perceptual learning: Neural mechanisms
Poster Presentation (36.514-36.528)
Sunday, May 8, 2:45 - 6:30 pm
- Perceptual learning: Plasticity and adaptation
Poster Presentation (16.537-16.546)
Friday, May 6, 6:45 - 9:30 pm
- Perceptual learning: Transfer and specificity
Oral Presentation (22.21-22.27)
Saturday, May 7, 10:45 - 12:30 pm
- Perceptual learning: Transfer and specificity
Poster Presentation (53.450-53.457)
Tuesday, May 10, 8:15 am - 12:15 pm
- Perceptual organization
Oral Presentation (34.11-34.17)
Sunday, May 8, 2:30 - 4:15 pm
- Perceptual organization: Contours and surfaces
Poster Presentation (26.401-26.419)
Saturday, May 7, 2:45 - 6:30 pm
- Perceptual organization: Mechanisms and models
Poster Presentation (63.318-63.329)
Wednesday, May 11, 8:15 am - 12:15 pm
- Perceptual organization: Segmentation and grouping
Poster Presentation (53.401-53.419)
Tuesday, May 10, 8:15 am - 12:15 pm
- Perceptual organization: Shapes and objects
Poster Presentation (43.301-43.318)
Monday, May 9, 8:15 am - 12:15 pm
- Scene perception: Features and categories
Poster Presentation (56.435-56.452)
Tuesday, May 10, 3:00 - 7:00 pm

- Scene perception: Memory and context
Poster Presentation (33.445-33.458)
Sunday, May 8, 8:15 am - 12:15 pm
- Spatial vision: Crowding
Oral Presentation (22.11-22.17)
Saturday, May 7, 10:45 - 12:30 pm
- Spatial vision: Crowding and eccentricity
Poster Presentation (53.542-53.555)
Tuesday, May 10, 8:15 am - 12:15 pm
- Spatial vision: Encoding and decoding
Poster Presentation (26.536-26.551)
Saturday, May 7, 2:45 - 6:30 pm
- Spatial vision: Mechanisms
Poster Presentation (26.521-26.535)
Saturday, May 7, 2:45 - 6:30 pm
- Spatial vision: Natural images
Oral Presentation (35.11-35.16)
Sunday, May 8, 5:15 - 6:45 pm
- Spatial vision: Neural and psychophysical mechanisms
Oral Presentation (54.11-54.18)
Tuesday, May 10, 2:30 - 4:30 pm
- Spatial vision: Summary statistics
Poster Presentation (53.534-53.541)
Tuesday, May 10, 8:15 am - 12:15 pm
- Temporal processing
Oral Presentation (61.11-61.17)
Wednesday, May 11, 8:00 - 9:45 am
- Temporal processing
Poster Presentation (33.539-33.557)
Sunday, May 8, 8:15 am - 12:15 pm
- Visual memory
Oral Presentation (34.21-34.27)
Sunday, May 8, 2:30 - 4:15 pm
- Visual memory: Capacity and resolution
Poster Presentation (63.401-63.422)
Wednesday, May 11, 8:15 am - 12:15 pm
- Visual memory: Encoding and retrieval
Poster Presentation (23.442-23.457)
Saturday, May 7, 8:15 am - 12:15 pm
- Visual memory: Objects and features
Poster Presentation (16.441-16.453)
Friday, May 6, 6:45 - 9:30 pm
- Visual search
Oral Presentation (62.21-62.27)
Wednesday, May 11, 10:45 - 12:30 pm
- Visual search: Elements, cues and configurations
Poster Presentation (53.429-53.449)
Tuesday, May 10, 8:15 am - 12:15 pm
- Visual search: Eye movements
Poster Presentation (23.321-23.329)
Saturday, May 7, 8:15 am - 12:15 pm
- Visual search: Natural scenes and practical tasks
Poster Presentation (56.401-56.411)
Tuesday, May 10, 3:00 - 7:00 pm
- Visual search: Neural mechanisms
Poster Presentation (56.412-56.418)
Tuesday, May 10, 3:00 - 7:00 pm

Entries are indexed by abstract number, not page number; **bold** entries indicate first author abstracts.
 "S" entries indicate symposia.

- A**
- Abdollahi, R - **33.435**
 Abe, S - 23.411
 Abegg, M - 56.533
 Abel, LA - 43.415
 Abrams, J - **53.542**
 Abrams, R - 36.413
 Achler, T - **33.550**
 Adam, J - 33.437
 Adamo, M - 24.16, **33.316**
 Adams, R - 33.451
 Adams, RJ - **33.311**
 Adams, WJ - 16.536, 33.446
 Adcock, RA - 63.431
 Adelson, E - **21.17**, 23.413
 Adelson, EH - 31.23
 Adini, Y - 16.401
 Adler, S - **33.313**, 53.449
 Adolphs, R - 56.510
 Agosta, S - **23.510**
 Agostini, R - 63.322
 Aguilar, C - 43.414
 Aguirre, G - 56.435
 Aguirre, GK - **43.447**, 53.533,
 56.504, 56.543, 63.324, 63.326
 Ahlstrom, U - 23.504
 Ahmad, N - **26.535**
 Ahn, J - **41.26**
 Ahumada, A - **51.27**
 Aihara, K - 36.303
 Ainslie, P - 16.545
 Ajina, S - 52.21
 Aks, D - **23.424**, 23.425, 23.428,
 53.327
 Al-Aidroos, N - **16.501**, 36.413
 Al-Rasheed, A - 36.310
 Alais, D - 36.423
 Albrecht, AR - **53.540**
 Aldcroft, A - 43.303
 Ales, J - 24.13, 43.329, **55.21**
 Alexander, R - **23.322**
 Algom, D - 33.430
 Allard, R - 23.436, **36.541**
 Allen, E - 16.533, **63.415**
 Allen, G - 56.429
 Allen, H - **56.549**
 Allenmark, F - **52.13**
 Alley, L - 23.424, **23.425**
 Allison, R - 63.441
 Allred, S - 42.12
 Allred, SR - **36.301**
 Almeida, R - **56.508**
 Alonso Prieto, E - **43.440**
 Altieri, N - **36.422**
 Altschuler, EL - 23.423, 63.445
 Alvarez, B - **36.314**
 Alvarez, G - 16.429, 16.450, 16.505,
 23.442, 23.456, 63.315, 63.404
 Alvarez, GA - 23.440, 34.21
 Alvarez, J - 36.310
 Alzahabi, R - 23.329, **56.554**
 Amano, K - **16.511**, 26.314, 43.406
 Amir, O - **53.526**, 56.534
 An, X - **26.401**, 26.411, 33.425
 Andersen, G - 55.22, 63.456
 Andersen, GJ - 22.21, 22.23
 Andersen, T - **36.452**
 Anderson, B - 26.422, 43.323
 Anderson, BL - **21.11**
 Anderson, DE - **63.403**
 Anderson, E - **53.548**
 Anderson, G - **53.311**
 Anderson, N - **16.402**, 43.316
 Andersson, R - 43.403
 Andrews, T - 43.446
 Andrews, TJ - 43.444, **43.445**
 Anker, S - 24.12
 Anstis, S - 16.533, 26.424, **31.11**,
 36.550
 Anton-Erxleben, K - **53.303**
 Appelbaum, LG - 16.541
 Archer, D - **63.422**
 Arcizet, F - **16.508**
 Arend, I - 23.303
 Arguin, M - 53.555
 Arieli, A - 16.401
 Armann, R - 56.306
 Arnell, KM - 26.447, 36.441
 Arnold, D - 33.412, 43.328, 55.17,
 61.17
 Arrighi, R - 33.549
 Arsenault, E - **26.536**
 Arslan, A - **56.516**
 Ash, J - 23.417
 Ashkenazy, Y - 56.501
 Aslin, RN - 24.14
 Astle, A - 41.11
 Atkinson, J - **24.12**, 26.511, 33.317
 ATSUMI, T - **23.501**
 Authié, C - **25.14**
 Avigan, P - 26.449
 Avni, C - 35.22
 Avraham, T - **62.23**
 Awh, E - 22.11, 63.403
 Axelrod, V - **35.21**
 Aydin, M - 34.17
 Aydin, SV - **63.455**
 Ayeroff, E - **23.442**
 Ayhan, I - **33.541**, 33.542, 33.545
 Aytekin, M - **36.401**
- B**
- B Mattingley, J - 56.536
 Babinsky, EE - **33.325**
 Backus, B - 16.542
 Backus, BT - 36.506, **36.508**, 53.454
 Bacon-Macé, N - 56.513
 Bacon, M - 55.15
 Badcock, D - 26.528, 56.508
 Badcock, DR - 56.503
 Badcock, J - 56.508
 Badke, C - 33.452
 Bae, GY - **23.426**, 23.431, 63.411
 Baek, J - **36.453**
 Baek, Y - **23.404**
 Bahrami, B - 23.508, 36.522, 52.16,
 52.17, **52.21**, 54.26, 63.421
 Bai, J - **53.436**
 Bainbridge, W - 34.24
 Baker, C - 16.423, 16.424, 25.16,
 26.536, 33.536, 41.16, 56.449
 Balas, B - 53.411, **53.537**
 Baldassano, C - **33.445**, 62.14
 Baldassi, S - 24.21
 Baldauf, D - **36.438**
 Bales, J - 32.13
 Ballard, D - 36.411
 Ban, H - **51.13**, 63.436
 Bang, J - 26.505
 Banks, M - 43.418, 52.11
 Banks, MS - 56.419
 Banno, H - **56.529**
 Banton, T - 36.412, 36.421
 Bao, M - **16.537**
 Bao, P - **16.426**
 Bar, M - 33.451, 56.530, 56.532
 Barbeau, E - 33.423, 33.456, 56.513
 Barbot, A - **26.421**
 Barch, D - 26.418
 Barenholtz, E - **56.538**
 Barghout, L - **53.405**
 Barnes, G - 52.17
 Barnes, N - **36.403**
 Barnes, T - **26.510**
 Baron-Cohen, S - 41.16
 Barr, S - 33.550
 Barragan-Jason, G - **33.423**
 Barrett, S - **56.330**
 Barron, J - **35.15**
 Barthelmé, S - 26.504
 Bartlett, M - 52.24
 Bartolomeo, P - 16.514
 Bartolucci, M - **36.521**
 Barton, J - 16.412, 23.544, 33.415,
43.426, 43.450, 56.533, 61.22,
 63.432, 63.434
 Barton, JJ - 23.538, 26.444, 33.414,
 43.428
 Baruch, O - **56.540**
 Baseler, H - **43.446**
 Bashir, S - 36.415
 Bastien, D - 63.325
 Bastien, R - 36.553
 Battaglia, P - **33.534**
 Battelli, L - 23.510, 43.326
 Battista, J - 56.503
 Baudouin, J - **56.317**
 Bauhoff, V - **23.326**
 Baumann, O - **25.15**, 56.536
 Baumgartner, F - **36.436**
 Bavelier, D - 53.420
 Bays, P - **63.417**, 63.421
 Beck, D - 53.307, 56.556
 Beck, DM - 26.436, 33.445, 33.455,
 36.440, 56.442, 62.14
 Beck, MR - 16.449, 16.453, **23.325**
 Beck, TF - **55.14**
 Beck, V - **53.438**
 Becker, L - **33.444**
 Becker, M - 23.453
 Becker, MW - **23.329**, 56.554
 Beckett, A - **26.515**
 Bédard, P - 53.457
 Bedford, R - **56.509**
 Beer, AL - 16.504
 Beers, A - 63.451
 Begus, K - 56.509
 Behrmann, M - 35.25, 63.321
 Beilock, S - 63.415
 Bell, J - 53.413
 Bellgrove, M - 33.405, 56.536
 Belopolsky, A - 23.443, **63.423**
 Ben-Shahar, O - **26.416**, 26.437,
 34.11, 56.440
 Ben-Yosef, G - 26.416, **34.11**
 Bendahman, L - 23.310
 Benedetti, D - **63.322**, 63.323
 Bennett, PJ - 21.21, 23.445, 26.527,
 36.433, 43.438, 56.511, 61.21,
 63.452, 63.453
 Bennetts, R - **33.427**
 Benoni, H - 41.25
 Benson, NC - **63.324**, 63.326
 Bentin, S - 23.528, 23.540, 53.301
 Benton, C - 33.539
 Berard, A - 36.516
 Berg, D - 16.422
 Berkes, P - 26.503
 Bernard, J - **22.13**, 53.551
 Besson, G - **33.456**
 Bettencourt, K - **53.318**
 Bettencourt, L - 16.441, 33.550
 Betts, L - **33.318**
 Bex, P - 33.301, 33.326, 35.13,
 43.433, 53.552, 63.306
 Bhattacharjee, A - 23.547
 Bi, Y - 53.321
 Bian, Z - 63.456
 Biederman, I - 31.21, 41.17, 53.526,
 56.534, **56.535**
 Bieniek, M - **16.434**
 Biggs, A - **33.514**
 Bilger, E - **26.433**
 Billington, J - **53.513**
 Billington, K - 51.27
 Billock, V - **26.333**
 Binda, P - 24.22, **53.302**
 Bingham, G - 33.441
 Bingham, GP - **33.429**, 33.442,
 63.457
 Binsted, G - 16.545, 33.428, 33.433
 Birmingham, E - 23.544, **61.27**

- Birtles, D - 24.12, 33.317
 Bischof, W - 23.544
 Bisley, J - 16.508, 56.414
 Bisley, JW - 23.519, 56.415
 Black, M - 33.415
 Blaha, L - 33.413, **52.26**
 Blake, R - 23.401, 36.327, 53.312
 Blakely, D - **33.501**, 33.509, 33.516
 Blakeslee, B - **16.526**, 63.448
 Blalock, L - **23.446**
 Blanchard, A - **63.424**
 Blanche, T - 43.405
 Blaxton, CL - **23.427**
 Blohm, G - 53.504
 Bloj, M - 26.305, 51.14
 Blondé, L - 43.419
 Bloomfield, T - 26.511
 Blundell, J - 51.13, 56.549
 Bocca, F - 41.14
 Bocheva, N - **33.518**
 Bochsler, TM - **53.514**
 Boehnke, S - 16.516
 Bogadhi, A - **36.537**
 Bojilov, L - 33.518
 Bonatti, L - 63.308
 Bonnef, Y - **16.401**
 Boot, W - 33.501, **33.509**, 33.516
 Boremanse, A - **43.441**
 Borji, A - **36.457**
 Born, S - 53.322
 Boshyan, J - 33.451
 Bosten, J - **42.13**
 Bourdev, L - **25.21**
 Bourns, K - 16.545, **33.433**
 Bouvier, S - **62.15**
 Bovik, A - 35.11, 51.12
 Bower, JD - **22.21**
 Bowman, H - 33.554
 Boynton, G - 16.515, 26.435, 53.419
 Boynton, GM - 53.302
 Bracci, S - **62.11**
 Braddick, O - 24.12, **26.511**, 33.317
 Brady, M - 53.527
 Brady, T - **16.450**, 23.456
 Brainard, D - 21.13, 42.12
 Brainard, DH - 63.324, 63.326
 Brand, J - **53.534**
 Brandman, T - **43.429**
 Brascamp, J - 53.312
 Braun, A - **23.520**
 Braun, J - **53.404**
 Braun, M - 23.309
 Braunstein, M - 55.22
 Bravo, M - **56.539**
 Breitmeyer, B - 16.446, 26.417, **43.313**
 Bremmer, F - 33.543
 Brenner, E - 23.552, 26.304, 43.417, **61.12**
 Brent, MH - 43.410
 Breska, A - 33.458
 Bressler, D - **36.325**
 Brewster, K - 16.421, **16.545**, 33.428, 33.433
 Bridgeman, B - **55.15**, 63.310
 Bridwell, D - **21.25**
 Brienza, V - 63.458
 Brierley, E - 23.551
 Brillhault, A - **23.311**
 Brining, E - 36.301
 Brischetto Costa, T - 33.406
 Brockmole, J - 23.546, 33.501, 33.509, 33.516, **53.531**
 Brodeur, M - **56.517**
 Brooks, D - **56.401**
 Brooks, K - 33.427
 Brown, A - 42.17
 Brown, J - 33.448
 Brown, JM - 26.430
 Brown, S - 26.450
 Browning, NA - 33.527
 Brumby, S - 16.441
 Bruno, A - 33.541, **33.542**
 Bryant, EJ - 23.526
 Bryant, L - 63.307
 Buia, C - 31.26
 Bukach, C - 56.547
 Bulakowski, PF - 63.317
 Bülthoff, H - 23.503, 56.306
 Bülthoff, HH - 23.441, 33.409, 56.423, 56.424
 Bülthoff, I - 23.527, **33.426**, 56.306
 Bundesen, C - 43.327, 56.507
 BUONANNO, F - 63.304
 Burakowski, L - **33.312**
 Burge, J - **52.12**
 Burke, D - 33.427
 Burke, M - 23.312, 33.443
 Burkhardt, A - 33.413
 Burn, S - 16.532
 Burnett, K - **26.420**
 Burns, S - 26.546
 Burr, D - 24.21, **24.22**, 26.324, 33.549, 52.15
 Burr, DC - 24.25
 Burra, N - **33.502**
 Burton, M - 43.446
 Busey, T - 33.413
 Bushmakina, M - 43.437
 Busigny, T - 23.534, 23.538, **61.22**
 Butler, A - **36.419**
 Butt, OH - 63.324, **63.326**
 Byers, A - **36.519**
- C**
- Cabrera, C - **26.501**
 Cacciamani, L - **43.454**
 Caddigan, E - 33.455, 53.329, **56.442**
 Caharel, S - 43.443
 Cain, M - 16.541
 Cain, MS - **56.411**, 63.431
 Calabrese, A - **43.414**
 Calabro, F - **63.303**
 CALABRO, F - 63.304
 Caldara, R - 16.419, 52.22, 56.303, 56.308, 61.25
 Calder, A - 35.24
 Calder, AJ - 25.23, 56.314
 Calleja, M - **53.448**
 Camerer, C - 53.530
 Cameron, I - 63.454
 Candy, TR - 33.325
 Cant, JS - **16.425**, 33.422
 Cantor, C - 16.539, 33.310
 Cantor, CR - **61.13**
 Cao, B - **16.527**
 Cao, D - 26.318
 Caplovitz, G - 16.540, 43.314, **63.305**
 Caplovitz, GP - 43.435
 Capps, M - 43.422
 Caramazza, A - 62.11
 Carbone, E - 23.314
 Cardin, V - **33.523**, 55.24
 Carlin, JD - **25.23**, 32.26
 Carlisle, N - **62.25**
 Carlson, T - 56.545, **56.553**
 Carmel, D - **36.319**, 52.16
 Carney, T - 36.501
 Carrasco, M - 21.24, 24.27, 26.421, 26.453, 36.319, 53.303, 53.542, 54.15
 Carrozzo, M - **33.548**
 Carter, B - **53.538**
 Carter, C - 26.418
 Casagrande, V - 32.25
 Casanova, C - **52.14**
 Casile, A - 23.318, 23.510
 Cass, J - 36.423
 Casserly, E - 33.429
 Casteau, S - **23.302**
 Castelhan, M - 23.321, 53.437
 Castet, E - 43.414
 Cate, A - **43.305**
 Cattaneo, L - 54.15
 Cauchoix, M - 56.516
 Caudek, C - **23.523**, 33.533, 51.17
 Cavanagh, P - 22.16, 24.23, 26.424, 31.11, 33.306, 36.550, 43.312, 51.24, 53.424, 53.553, 63.318
 Cave, K - 53.447
 Cavérian, C - 56.450, **56.451**
 Cavina-Pratesi, C - 62.11
 Caziot, B - 16.542, **53.454**
 Ceccaldi, M - 33.456
 Cecchetti, L - 33.549
 Cello, F - 63.322
 Cha, J - **23.447**, 26.443
 Cha, O - 23.404
 Chai, A - 33.408
 Chakravarthy, R - 22.14, **36.437**
 Chaminade, T - 55.25
 Chan, E - 25.15, **56.536**
 Chan, L - **53.434**
 Chanceaux, M - **23.310**
 Chanes, L - **36.445**
 Chang, AS - 16.536
 Chang, C - **36.404**
 Chang, DH - **63.438**
 Chang, L - 42.22, 42.23
 Chang, Y - 63.425
 Chaparro, A - 36.531
 Charpentier, C - 16.508
 Charron, C - 25.11
 Chasteen, A - 53.326
 Chatterjee, G - 23.536, **23.543**
 Chaudhuri, A - 36.507
 Chauret, M - 56.517
 Chauvin, A - **23.309**, 56.452
 Chavillaz, A - 26.442, **56.404**
 Chazut, E - 33.430
 Cheimets, C - 56.302
 Chen, C - **26.522**, 33.419, 36.326, 63.329
 Chen, J - **53.549**
 Chen, L - 25.25, 33.323, 36.427, 54.22, 56.537
 Chen, M - 53.514
 Chen, N - **16.546**
 Chen, Q - **26.415**
 Chen, W - 23.430
 Chen, X - 36.427
 Cheng, A - 36.429
 Cheng, CK - **16.420**
 Cheng, D - 33.428
 Cheng, J - **53.512**, 53.518
 Cherici, C - **23.319**
 Cheung, O - **56.532**
 Chiang, AD - **16.422**
 Chica, AB - 36.445
 Chien, SH - **33.323**
 Chima, AS - 53.543
 Chisholm, J - **33.503**
 Chiu, MK - **53.550**
 Cho, H - 56.553
 Choi, H - **16.544**
 Chokron, S - **56.450**, 56.451
 Cholewiak, S - 26.325, 63.314
 Cholewiak, SA - **51.15**
 Chong, E - **63.309**
 Chong, SC - 23.404, 33.457, 56.528
 Choo, H - **26.446**
 Chopin, A - **23.401**
 Chow, DH - 33.314, **33.322**
 Chrastil, E - **36.405**
 Christensen, A - **55.27**
 Christensen, BK - 56.511
 Christian, M - 23.309
 Christiansen, J - **56.507**
 Chu, H - **33.455**
 Chu, W - **23.448**, 63.412
 Chua, FK - **33.504**, 43.412
 Chubb, C - 34.16, 36.428, 63.328
 Chun, M - 34.24, 43.317
 Chun, MM - 53.540
 Chung, H - 63.425
 Chung, S - 22.13, **22.15**, 33.408, 53.551
 Church, J - 33.311
 Churchland, A - 32.11
 Cicchini, GM - **33.549**
 Cicchini, M - 24.22, 41.14
 Cinelli, M - 53.515
 Cisarik, P - **43.423**
 Clark, JJ - 53.426
 Clark, K - **63.431**
 Clarke, J - **16.519**, 23.457
 Clarke, S - 32.16
 Clegg, B - 23.446
 Clements-Stephens, A - **53.415**
 Clery, S - **26.305**
 Clifford, A - 36.308, 36.310
 Cloete, S - **25.12**, 52.25
 Coates, D - 22.13, **53.551**
 Coats, R - 33.441, 33.442, **63.457**
 Coelho, C - 52.25
 Coen Cagli, R - 16.415
 Cohan, S - **23.542**, 56.307
 Cohen, MA - **63.404**
 Cohen, N - **56.428**
 Colas, J - 16.520, 36.512
 Cole, F - **23.413**
 Colino, F - 16.545, **33.428**, 33.433
 Collet, K - 43.453
 Collimore, L - 16.420
 Collins, T - **51.23**

- Coltheart, M - 53.448
 Conci, M - **53.439**, 54.23
 Cong, L - 22.24
 Coningham, A - 63.301
 Connolly, AC - **56.514**
 Conrath, J - 43.414
 Consonni, M - 41.14
 Constantinidis, C - 32.23
 Conte, M - 26.541
 Cook, R - **33.545**
 Cooper, A - 55.15
 Cooper, EA - **56.419**
 Corbett, J - **53.406**
 Cormack, L - 35.11, 51.12
 Cormack, LK - 33.522
 Corraia, S - 33.306
 Corrow, S - 23.536, 33.315, **56.327**
 Cosman, J - **54.27**
 Cosman, JD - 53.320
 Cottureau, B - **43.329**
 Cottrell, G - 25.24
 Coubard, O - 56.450, 56.451
 Courage, ML - 33.311
 Cowan, F - 24.12
 Crabbe, F - 23.504
 Crane, D - 33.454
 Creem-Regehr, S - 56.429, 56.433
 Creem-Regehr, SH - 53.508, 56.431
 Creighton, SE - 21.21
 Crewther, D - **56.506**, 56.506
 Crewther, S - 56.506, **56.541**
 Crognale, MA - 36.443
 Crookes, K - 23.522, **56.304**
 Cross, A - 56.541
 Crouzet, SM - 23.311, **43.422**
 Crowell, J - 56.550
 Cucchiara, BL - 56.504
 Cui, J - **16.403**
 Culham, J - 55.11, 56.425
 Culmer, DP - 36.420
 Cunningham, C - **56.408**, 56.409
 Curby, KM - **23.525**
 Curran, T - 23.450, 25.26
 Curran, W - **33.539**
 Curtis, C - 53.316
 Cusack, R - 32.26, **34.23**, 56.447
 Czuba, TB - **33.522**
-
- D**
 d'Avossa, G - 26.420
 D'Lauro, C - **36.520**
 Da Costa, SE - 32.16
 Dai, J - 56.401
 Dakin, S - 33.326, 53.535, 53.536,
 53.548, **54.18**, 56.553
 Dal Martello, M - 61.26
 Dale, G - **26.447**
 Dalhaus, III, R - 26.316
 Dalrymple, K - **23.544**
 Dambacher, M - **63.318**
 Damesghi, N - 56.428
 Danckert, J - 43.323, 53.323
 Dandekar, S - 53.316
 Danielson, A - 33.556
 Danielson, E - 43.437
 Das, K - 36.442
 Dasgupta, S - 43.326, **56.309**
 Daskagianni, E - 56.538
 Dassonville, P - **34.12**, 63.320
 Datta, R - **56.504**, 63.324, 63.326
 David, H - 52.11
 David, K - **52.11**
 Davidenko, N - 33.424, **43.448**
 Davidson, M - **16.427**
 Davies-Thompson, J - **43.444**,
 43.445
 Davies, R - 26.548, **33.304**
 Davis, M - 23.513
 Davoli, C - **23.546**
 Daw, N - 55.12
 de Gelder, B - 33.406, 33.410
 de Grosbois, J - 33.428
 de Heering, A - **33.420**
 de la Malla, C - **23.550**
 de Lussanet, MH - **23.505**
 de Ridder, H - 56.420
 Debono, K - **36.536**
 Dechter, E - **36.512**
 DeGutis, J - 16.503, 26.432
 DeGutis, JM - 23.542, **33.431**, 56.307
 Del Viva, MM - 63.322, **63.323**
 DeLoss, DJ - **22.23**
 Demeyere, N - **16.502**
 Denison, R - **23.412**
 Denisova, K - 26.325, **43.308**
 Dennet, H - 36.403
 Dennett, HW - **33.411**
 Deouell, L - 33.458
 Deroche, M - 33.416
 Desa, S - 16.420
 DeSimone, K - **26.518**, 33.324
 DeSouza, J - **26.321**
 Detre, JA - 56.504
 Deubel, H - 24.23, 56.552
 Dewhurst, R - **43.402**
 Dhandhanian, K - **36.431**
 Di Noto, P - 26.321
 Diamond, A - **33.412**
 Diaz, G - **23.518**, 55.16
 Dickinson, C - **33.454**
 Dickinson, JE - 26.528, 56.503,
 56.508
 Didic-Hamel Cooke, M - 33.456
 Dieter, KC - **26.327**
 DiGiacomo, A - **53.304**
 Dilks, D - 43.451
 Dilks, DD - 36.525, **62.13**
 Dion-Lessard, G - 56.517
 Dionne-Dostie, E - 56.517
 Ditye, T - **36.522**
 Dixon, E - 16.532, 41.16
 Dobbins, A - **63.307**
 Dobkins, K - **56.328**
 Dobres, J - **36.514**
 Dobson, K - 16.522
 Dodd, M - **16.410**
 Dody, Y - 56.501
 Doerrfeld, A - **63.312**
 Dombrowe, I - **26.429**
 Domini, F - 23.523, 33.533, 51.17
 Donk, M - 26.429
 Donnelly, N - 53.447
 Donner, TH - 26.516
 Donovan, I - **26.448**
 Doon, J - **56.407**
 Dorr, M - **33.301**
 Dosani, M - **43.428**
 Doshier, B - 23.448, 26.501, 36.453,
36.503, 42.24, 63.412
 Doshier, BA - 41.22
 Doucet, G - 56.450
 Dougherty, R - 33.557
 Dovencioglu, DN - **53.453**
 Doyen, D - 43.419
 Drew, T - 56.408, **56.409**
 Drewes, J - **51.21**
 Driver, J - 26.428, 55.25, 63.416
 Drover, JR - 33.311
 Druker, M - **26.422**
 Drummond, L - **63.435**
 Du, X - **56.537**
 Dubois, J - **26.519**
 Dubois, M - 31.27, **32.15**
 Duchaine, B - 23.538, **23.539**
 Dudek, J - 33.313
 Dugué, L - **56.412**
 Duijnhouwer, J - **33.552**
 Dukewich, KR - **53.324**
 Dumoulin, SO - 54.12
 Duncan, CS - 36.443
 Dunkley, B - **36.535**
 Dunlop, J - 33.425
 Dunsmoor, JE - 56.411
 Durand, F - 23.413
 Durand, K - 56.317
 Durant, S - 61.17
 Durgin, F - 23.547, 33.440, **56.430**
 Dux, P - 21.26, 43.328
 Dux, PE - 16.525
 Dyde, R - **56.542**
 Dye, A - 23.406
-
- E**
 Eckstein, M - 23.323, 36.456, 56.416,
 62.17
 Eckstein, MP - 36.442, 51.26, 56.418,
 61.24
 Ed, V - 36.512
 Edwards, D - 24.12
 Edwards, J - 36.448
 Edwards, M - 33.411, 43.431, **63.301**
 Egan, E - 51.16
 Egan, EJ - **23.414**
 Egeth, H - 62.26
 Ehinger, K - **31.22**
 Elbich, DB - 56.325
 Elfanagely, O - **23.428**
 Ellemberg, D - 56.448
 Elliott, J - **43.319**
 Elliott, JC - 36.442
 Elliott, S - **26.318**
 Emert, P - 53.409
 Emmanouil, TA - **26.449**
 Emrich, SM - **63.402**, 63.458
 Endres, D - 55.14
 Endress, A - **63.406**
 Engel, S - 16.537, 26.533
 Englund, J - **56.502**
 Ennis, R - **42.15**
 Enns, JT - 53.324
 Epstein, R - 56.435, 56.436, 56.446,
 62.15
 Erickson, G - 43.425
 Ericson, JM - **16.453**
 Erlichman, G - 23.435, **26.404**
-
- Erol, M - 16.519, 23.457
 Esins, J - **23.527**
 Essock, EA - 26.526, 26.540
 Ester, E - **22.11**
 Esterman, M - **16.503**, 26.432
 Evans, K - **56.441**
 Ewbank, M - **35.24**
 Ewbank, MP - 56.314
-
- F**
 Fabiani, M - 36.440
 Fabre-Thorpe, M - 56.512, 56.513
 Factor, L - 63.430
 Fadiga, L - 43.409
 Fahle, M - 43.422
 Fajen, B - 23.518, **25.13**, 53.505,
 53.519
 Fajen, BR - 53.502
 Falikman, M - 16.524
 Fang, F - 16.517, 16.546, **33.419**,
 53.416, 53.549
 Fantoni, C - **33.533**, 51.17
 Farber, LE - **26.527**
 Farell, B - **63.444**
 Farid, H - 56.539
 Farzin, F - **24.15**
 Faubert, J - 23.436, 36.541
 Faure, G - 43.414
 Favata, A - 16.404
 Favelle, S - 23.522, 56.304
 Fehd, HM - 23.427
 Fei-Fei, L - 33.445, 56.442, 62.14
 Feigenson, L - 16.445
 Feinberg, D - 56.323
 Feldman Barrett, L - 33.451
 Feldman, J - 26.402, 26.403, **34.14**,
 43.306, 43.307, 43.308, 43.311,
 63.314
 Felgueiras, P - 26.307
 Felsovalyi, O - 16.427
 Fencsik, D - **53.431**, 53.440
 Feng, L - 36.526
 Ferber, S - 63.402, 63.458
 Feria, C - **23.429**
 Fernandez Cruz, AL - 33.409
 Fernandez, J - 63.444
 Fesi, J - **33.524**
 Fiacconi, CM - **36.433**
 Field, D - 53.513
 Filangieri, C - **23.416**
 Fischer, J - **54.16**
 Fiser, J - 24.14, 26.503, **42.26**, 43.433,
 63.306
 Fisher, M - 33.437
 Fiske, S - **62.24**
 Fitzgibbon, A - 56.422
 FitzGibbon, E - 36.529
 Flatters, I - **36.420**
 Fleming, R - **21.15**, 51.15
 Fleming, RW - 63.437
 Flevaris, A - 23.528, **53.301**
 Flombaum, J - 16.447, 23.426,
 23.431, **63.411**
 Flusberg, S - **33.424**
 Foerster, R - **23.314**
 Fogelson, SV - 26.308, **62.12**
 Foley, NC - **36.455**
 Folstein, J - **56.518**

- Ford, J - 36.533
 Formankiewicz, MA - 26.535, **53.543**, 53.547
 Fortenbaugh, FC - **53.544**
 Foster, DH - **26.314**, 43.406
 Fougny, D - **34.21**
 Foulkes, AJ - 33.525, **33.526**
 Foulsham, T - 43.402
 Frackowiak, RS - 32.16
 Francis, G - 26.310, **26.315**
 Francis, S - 26.515
 Franconeri, S - 26.446, 53.305, 53.410, 53.422, 53.423, **54.21**, 63.311
 Franconeri, SL - 41.24
 Frank, SM - **16.504**, 53.442
 Franklin, A - 26.452, 36.308, **36.310**
 Franz, VH - 33.438
 Freeman, B - 23.413
 Freeman, T - 36.535
 Frenz, H - 36.408
 Freud, E - 33.430
 Fricker, D - 16.404
 Fried, M - 16.401
 Fries, P - 32.24
 Frith, C - 55.25
 Frost, A - 63.451
 Froyen, V - 34.14, **43.306**, 43.311
 Fu, X - 33.453
 Fuda, C - **53.449**
 Fukase, T - 26.311
 Fukiage, T - **36.554**
 Fukuda, K - **23.452**, **26.311**, 26.319, 26.532, 53.517, 63.418
 Fuller, SG - 36.508
 Fulvio, J - 26.507
 Fulvio, JM - **36.504**
 Fusco, R - 56.308
-
- G**
 Gabbard, SR - **36.555**
 Gabrieli, JD - 23.440
 Gage, R - 53.514
 Gagnon, KT - **56.431**
 Gajewski, D - 56.428
 Gallagher, A - 63.325
 Galperin, H - **63.306**
 Gambino, A - 36.301
 Gandhi, T - 41.13
 Ganel, T - **33.430**
 Gao, T - **53.425**
 Gao, Z - **23.528**
 Garber, M - 23.530
 Garcia, A - **53.452**
 Garcia, J - 23.509
 Gardner, P - 53.501
 Garrido, L - **33.422**
 Garrigan, P - **43.309**
 Garrod, O - 52.22
 Gaspar, C - 36.449, 36.451
 Gaspar, J - **16.518**, 56.550
 Gaudio, J - **36.556**
 Gaudry, I - 56.451
 Gauthier, I - 22.17, 56.305, 56.518
 Gegenfurtner, K - 23.317, 26.303, 33.547, 36.302, 36.536, 56.438
 Gegenfurtner, KR - **36.534**
 Geisler, W - **35.12**, 35.14, 52.12, 54.17
 Geisler, WS - 42.14
 Geng, J - 33.510, 63.422
 George, J - 16.441, 33.550
 Georgeson, M - **23.405**, 36.543
 Gerbino, W - **56.519**
 Geringswald, F - 36.436
 Germiné, L - 56.301
 Getov, S - 52.21
 Getty, D - 56.407
 Geuss, M - **56.429**
 Geuss, MN - 53.508
 Ghara Gozli, D - 53.304
 Gharib, A - **56.510**
 Gheorghiu, E - **34.13**, 53.408
 Ghose, T - **25.22**, 26.404
 Giaschi, D - 33.331
 Giavarini, C - 56.452
 Gibson, B - 33.514
 Giesbrecht, B - 21.27, 36.442, 43.319, 53.317, 56.416, 56.418, 62.17
 Giese, MA - 55.14, 55.27
 Giesel, M - **26.313**, 26.317
 Gilad-Gutnick, S - **23.521**
 Gilad, M - 56.501
 Gilaie-Dotan, S - **23.508**
 Gilani, SO - **43.412**
 Gilchrest, A - 33.315
 Gilchrist, A - 16.528, **42.11**, 42.12
 Gill, J - **16.505**
 Gillam, B - **63.443**
 Gilmore, R - 33.524
 Gilmore, RO - 56.325
 Gilson, S - 56.422, 56.432
 Giusti, M - 33.549
 Glaser, J - 53.329
 Glasser, DM - **63.302**
 Glennerster, A - **56.422**, 56.432
 Globa, AK - **33.330**
 Gmeindl, L - 53.310, **63.419**
 Goffaux, V - **43.430**, 43.453
 Goh, C - 63.416
 Gohar, B - 16.421
 Golarai, G - 23.541
 Gold, J - 26.418
 Goldberg, T - 35.22
 Goldsmith, M - 56.540
 Golomb, J - 33.305, **33.308**
 Gomez, A - 63.433
 Gong, H - 26.401, 26.411
 Gong, M - **33.453**
 Gonzalez, C - **23.312**, 56.522
 González, EG - 43.410
 Goodale, M - 33.404, 43.303, 55.11, 56.425
 Goodale, MA - 36.418
 Goodhew, SC - **16.525**
 Gordon, I - **52.24**
 Gordon, R - 56.525
 Gorea, A - **61.14**
 Gorgoraptis, N - 63.421
 Gori, M - **26.324**
 Goris, R - **26.542**
 Gorlin, S - 41.13
 Gors, J - 61.23
 Goryo, K - 23.411
 Gottesman, C - **33.450**
 Gould, M - **36.410**
 Gout, O - 56.450, 56.451
 Gozli, D - 33.437, **53.326**
 Grabowecky, M - 21.22, 23.402, 32.12, 33.546, 36.426, 56.402, **63.430**
 Grady, JP - 26.523
 Graf, EW - 16.536, 33.446
 Grafton, ST - 56.418
 Graham, D - **16.534**
 Grainger, J - 23.310
 Granger, RH - 62.12
 Granrud, C - **33.315**, 56.327
 Granzier, J - **36.302**
 Gratton, G - 36.440
 Gray, A - 23.544
 Gray, L - 33.329
 Grayhem, R - 26.320
 Green, CS - **26.507**, 36.504, 53.420
 Greenberg, AS - **63.321**
 Greene, C - 23.305, 54.12
 Greene, MR - **51.25**, 56.406
 Greenlee, MW - 16.504, 53.442
 Greenspon, E - 56.547
 Greenwood, J - **33.326**, 53.535, 53.548, 54.18
 Grewal, PS - **26.444**
 Griffin, H - **23.529**
 Griffith, A - 36.446
 Grill-Spector, K - 23.541, 43.448, 53.525
 Griscom, WS - **36.311**
 Gronau, N - **33.447**
 Groppo, M - 24.12
 Grosbras, M - 16.419
 Gross, EB - 36.412, 36.421
 Grossberg, S - 36.455
 Grossman, E - 23.509
 Grossman, ED - 43.326, 56.309
 Grove, P - 26.332
 Grueschow, M - **36.523**
 Guenther, B - 33.448
 Guenther, BA - **26.430**
 Guidi, S - **26.414**
 Gunther, KL - **26.316**
 Guntupalli, JS - **16.428**, 56.514
 Guo, F - 36.456, **56.416**, 62.17
 Gureckis, TM - 63.319
 Guyader, N - 23.309, 56.452
 Guzman-Martinez, E - **32.12**, 33.546
-
- H**
 H. Brainard, D - 36.304
 Haas, J - 16.510
 Habekost, T - 56.507
 Haberkamp, A - **63.429**
 Haberman, J - **16.429**
 Hackney, A - **53.515**
 Hadad, B - 26.410
 Hadley, H - **56.318**
 Hafed, Z - **51.22**
 Hagler Jr, DJ - 26.428
 Hahn, U - 23.554
 Haist, F - **24.16**, 33.316
 Hajcak, G - 56.417
 Haji Abolhassani, A - **53.426**
 Haladjian, H - 23.424, 23.425, 23.428, **36.446**, 53.327
 Halberda, J - 36.510, **63.409**, 63.414, 63.420
 Halchenko, YO - 62.12
 Halen, K - **33.418**
 Hallum, LE - **54.13**
 Ham, M - **16.441**, 33.550
 HAMALAINEN, M - 63.304
 Hamker, FH - **33.307**
 Hammarsten, C - 53.412
 Hammer, R - **53.525**
 Hammons, J - 16.510
 Hamrick, J - 33.534
 Han, J - **23.449**, 24.16, 33.316, 53.532
 Han, SW - **26.423**
 Hancock, P - 43.434
 Hanke, M - 36.436, 62.12
 Hanlon, K - **16.421**
 Hansen, BC - **56.448**
 Harasawa, M - **53.427**
 Harel, A - **56.449**
 Harman James, K - 36.419
 Harman, C - 23.425, **53.327**
 Harmatz, ES - 23.521
 Harms, R - **23.315**
 Haroz, S - 55.26
 Harris, J - 51.14
 Harris, JM - 26.305, 43.420
 Harris, L - 56.542
 Harrison, E - 33.331
 Harrison, HS - **53.516**
 Harrison, SA - **56.305**
 Harrison, W - **53.315**
 Hartendorp, M - **56.520**
 Harvey, B - 54.12
 Harvey, EC - 36.433
 Harvey, M - 16.419, **33.432**
 Hasegawa, H - 43.301
 Hatori, Y - **16.435**
 Haun, A - **26.537**
 Haun, AM - 26.526
 Haxby, J - 16.428
 Haxby, JV - 56.514, 62.12
 Hayashi, I - **53.407**
 Hayes, J - **36.544**
 Hayes, T - **43.401**
 Hayhoe, M - 35.14, 36.411
 Haynes, J - 26.516, **26.543**, 36.523, 63.433
 Hayward, W - **23.522**, 23.533, 53.434, 56.304, 56.305
 He, D - 33.419, **53.416**
 He, L - **25.25**
 He, S - 22.16, 23.512, 26.322, 26.533, 31.16, 33.521, 53.436
 He, Y - 53.549
 He, ZJ - 26.412
 Heath, M - **23.307**, 23.308, 33.434
 Hebart, M - 36.320
 Hebart, MN - **26.516**
 Hecker, E - 21.25
 Heeger, DJ - 21.24, 26.550
 Hein, E - **43.312**
 Heinemann, A - 53.446
 Heinen, S - **36.533**
 Heinke, D - 53.311
 Heinzle, J - 26.543
 Heitz, R - 36.439
 Helman, S - 36.410
 Helseth, S - 54.21
 Hemsworth, L - 33.523
 Henderson, CM - **56.521**

- Henig, D - 33.554
 Henriques, D - 36.417
 Henson, R - 35.24
 Heran, F - 56.450
 Herlihey, TA - **25.11**
 Hermetet, K - 56.330
 Heron, J - 23.455
 Herrmann, K - **21.24**, 53.303
 Herron, T - 43.305
 Herzmann, G - **23.450**
 Herzog, M - **22.22**, 34.17
 Herzog, MH - 26.531
 Hess, R - 36.543
 Hessels, R - 36.322
 Hestermann, D - 43.430
 Hetley, RS - **41.22**
 Hibbeler, P - 26.524, 53.404
 Hibbeler, PJ - **53.403**
 Higgins, J - 34.22
 Hilchey, M - **16.417**
 Hisakata, R - **31.13**
 Ho, T - **26.450**
 Hock, H - 33.520, 36.510
 Hodgins, J - 23.511
 Hoffart, L - 43.414
 Hoffman, D - 43.418
 Hogendoorn, H - **31.14**
 Holcombe, A - **23.430**, 61.12
 Holec, V - 26.425
 Hollands, M - 56.558
 Hollingworth, A - 16.410, 16.416,
 33.303, 53.438
 Holmes, S - 23.308, **33.434**
 Holmin, J - 63.451
 Holmqvist, K - 43.402, **43.403**
 Holcombe, A - 61.15
 Holtmann-Rice, D - 53.401
 Hon, AJ - 23.423
 Hong, S - 63.407
 Hong, SW - **42.16**
 HONMA, M - 43.413
 Horiguchi, H - **33.557**
 Horiuchi, K - **26.312**
 Horner, M - **33.402**
 Horowitz, T - 23.435, **53.430**, 53.431,
 53.440
 Horowitz, TS - 23.441
 Hosein, A - 23.534
 Hou, C - 24.15
 Hou, F - **36.526**
 Hou, Y - **36.450**
 Howell Young, M - **36.439**
 Hsieh, P - **16.520**, 36.512
 Hu, B - **26.326**, 26.327
 Hu, S - **26.451**
 Huang, AE - 23.423, 63.445
 Huang, C - **33.327**, 36.526
 Huang, H - **16.409**
 Huang, J - **23.445**
 Huang, S - **63.425**
 Huang, T - **36.524**
 Huang, X - 36.556
 Hubert-Wallander, B - 26.435
 Hudson, T - 33.439
 Hudson, TE - 43.424
 Huff, M - 23.326, 23.437, **53.428**
 Hughes, J - 23.417
 Huk, AC - 33.522
 Hulleman, J - 23.327, **53.432**, 56.413
 Humphreys, G - 16.502, 26.429,
 41.26, 53.306, 53.311
 Humphreys, GW - 26.440, 62.22
 Hurlbert, A - 21.16, 36.307, **41.15**
 Hurwitz, M - 43.323, 53.323
 Husain, M - 63.417, 63.421
 Hussain, Z - **41.11**
 Hutchinson, C - 56.549
 Huxlin, KR - 33.529
 Hwang, K - 33.524
 Hyde, D - **16.452**
 Hymel, A - **43.325**, 43.408
 Hyun, J - 23.449, 23.451, 56.557
-
- I**
 Iarocci, G - 61.27
 Ichikawa, H - **56.319**, 56.321
 Ichikawa, M - **33.555**
 IDE, M - **36.435**
 Ietswaart, M - 62.11
 Igarashi, R - 43.421
 IKEYAMA, H - 43.413
 Ikkai, A - **53.316**
 Ilg, W - 55.27
 Im, HY - **63.420**
 Imai, C - **36.303**
 Imai, H - **32.27**
 Ing, A - **26.538**
 Intoy, J - 56.313
 Iordan, MC - 33.445, **62.14**
 Ishibashi, K - **53.435**
 Ishii, M - **43.421**
 ISHIKANE, H - **26.509**
 Ishikane, H - 53.427
 Ishiwata, T - 26.330
 Ishuguro, H - 55.25
 Isola, P - **16.442**
 Issen, L - **33.529**
 Itier, R - 23.328, 43.449
 IPIER, R - 33.403
 Itti, L - 16.408, 16.422, 36.404,
 36.457, 56.316, 63.454
 Ivanov, P - **43.405**
 Ivory, S - **16.528**, 42.11
-
- J**
 Jack, R - **52.22**
 Jacob, J - **16.446**, 26.417, 43.313
 Jacobs, RA - 34.26
 Jacono, M - 43.409
 Jacques, C - **43.453**
 Jahn, G - 23.437, 53.428
 Jain, A - 33.535, **36.506**, 36.508
 James, T - **43.437**
 Janczyk, M - 53.446
 Jang, SO - 36.544
 Jansen, M - **26.317**
 Jardine, NL - **23.433**
 Jarodzka, J - 43.402
 Jarudi, I - 23.520
 Jarvstad, A - **23.554**
 Jastorff, J - **23.502**, 33.435
 Jaworska, K - 36.324
 Jefferies, LN - **53.310**, 63.419
 Jeffery, L - 23.537, 33.413
 Jehee, J - 42.21
 Jelinek, S - 23.329
-
- Jemel, B - 23.534, 43.455
 Jenkins, R - 43.446
 JEON, ST - **33.328**
 Jeong, SK - **16.512**
 Jeter, P - 36.503
 Ji, Z - 16.441
 Jiang, Y - 16.433, 23.512, **23.516**,
 32.25, 33.407, 33.540, 36.321,
 53.314
 Jin, Y - 43.411
 Jobst, C - 26.321
 Jogan, M - **31.12**
 Johnson, A - 35.16, **56.443**
 Johnson, AP - 56.448
 Johnson, M - **34.22**, 34.22
 Johnson, R - **33.443**
 Johnson, S - 33.312
 Johnston, A - 23.529, 33.541, 33.542,
 33.545, 36.551
 Johnston, S - 23.538
 Jolmes, N - 23.311
 Jonathan, S - 53.305
 Jones, J - 33.516
 Jonikaitis, D - **56.552**
 Joo, E - 23.447, 26.443
 Joo, SJ - **53.419**
 Joordens, S - 16.420
 Jordan, G - 36.307
 Joseph, C - **63.426**
 Josephs, JA - **33.446**
 Joukes, J - **36.542**
 Juan, C - 56.535
 Julian, JB - **36.525**, 62.13
 Juni, MZ - **63.319**
 Jurs, B - **33.413**
-
- K**
 K. Yamaguchi, M - 56.320
 Kaczmarek, H - 56.550
 Kadar, I - **56.440**
 Kaemmerer, M - 23.511
 Kahn, DA - 43.447, **56.543**
 Kahn, LE - **41.24**
 Kahnt, T - 26.543, 36.523
 Kaiwi, J - 51.27
 Kakigi, R - 56.320, 56.321
 Kalia, A - **26.323**
 Kallie, CS - 53.514
 Kamesaki, C - 36.305
 Kanai, R - 23.508, 24.11, 36.522,
52.16, 52.17
 Kanan, C - **25.24**
 Kanaya, H - **23.434**
 Kanaya, S - 26.330, **36.430**
 Kanazawa, S - 33.320, 56.319,
 56.320, 56.321, 56.326
 Kaneko, H - 33.320, 53.517
 Kaneko, S - **16.529**
 Kanematsu, E - **36.304**
 Kang, D - **42.22**, 42.23
 Kang, H - **56.557**
 Kang, M - **36.327**
 Kang, P - **31.25**
 Kang, X - 43.305
 Kantor, B - 23.410
 Kanwisher, N - 16.520, 33.305,
 33.308, 36.525, 43.451, 56.310,
 62.13
-
- Kaplan, E - 53.447
 Kapoor, M - 23.305
 Kar, K - **26.512**
 Karas, R - **63.449**
 Karidas, S - 36.448
 Kashiwase, Y - **36.447**
 Kasper, RW - **56.418**
 Kass, R - 36.520
 Kastner, S - 16.432, 16.507
 Katsuki, F - **32.23**
 Katsumura, M - **26.413**, 26.419
 Katyal, S - **23.305**
 Kaulard, K - **33.409**
 Kawahara, J - 26.426, **56.551**
 Kawahara, T - 53.506
 Kawashima, Y - **53.517**
 Kay, K - **26.544**
 Keane, B - 23.417, 23.435, **26.405**
 Keane, BP - 26.418
 Keeble, DR - 23.526
 Keil, F - 33.449
 Keith, G - 26.321
 Kellman, P - 23.435, 26.404, 26.405,
 43.309, 53.450
 Kellman, PJ - 43.301
 Kelly, J - **53.455**
 Kelly, K - **33.324**
 Kelly, N - 56.549
 Kempgens, C - **43.302**
 Kempster, B - **56.522**
 Kennedy, A - **23.548**, 36.424
 Kennedy, BL - 16.522, **63.427**
 Kenyon, G - 16.441, 33.550
 Kerrigan, IS - **16.536**
 Kersten, D - 26.507, 26.533
 Kerzel, D - 33.502, 33.512, **53.322**
 Khan, A - **36.417**
 Kharkwal, G - **56.445**
 Kibbe, MM - **26.325**
 Kiesel, A - 53.446
 Kihara, K - **26.426**
 Killingsworth, S - **26.452**, 43.408
 Kim, D - **23.451**, 26.505, 32.27,
36.516
 Kim, J - 21.11, **26.310**, 26.315,
 33.427, **43.418**
 Kim, JG - **56.534**, 56.535
 Kim, M - **21.14**
 Kim, S - 26.325, **26.403**, 34.14, 34.14,
43.307
 Kim, Y - 41.21
 Kim, YJ - **26.443**, **26.526**, 26.540,
53.309
 Kimchi, R - 43.315, 56.540
 Kimura, E - 16.530, **23.411**
 Kimura, H - 36.540
 Kindy, E - 43.423
 Kinerk, W - **26.529**
 King, K - 23.536
 King, M - 16.403
 Kingdom, F - 54.18
 Kingdom, FA - 34.13, 53.413
 Kingstone, A - 16.402, 23.544,
 33.503, 43.439
 Kita, S - 53.435
 Kitazaki, M - 23.515, 53.456
 Kittler, J - 16.406
 Kiya, K - 53.517
 Klee, D - 22.11

- Klein, R - 16.417
 Klein, S - 22.26, **36.501**
 Kleinholdermann, U - **33.438**
 Klink, C - **26.513**
 Klobusicky, E - 53.420
 Kloos, U - 56.423
 Knill, D - 26.326, 36.513
 Knill, DC - 26.327, 33.529, 34.26
 Knöll, J - **33.543**
 Knox, P - 33.329
 Ko, H - **53.402**
 Kobayashi, M - **56.320**
 Koch, C - 26.519
 Koehler, K - **36.456**
 Koenderink, J - 56.420
 Koenig-Robert, R - **16.430**
 Koesling, H - 23.314
 Kogo, N - **43.311**
 Kohler, PJ - 16.504, **26.308**, 62.12
 Koida, K - 53.456
 Koldewyn, K - **56.310**
 Kolodny, T - 56.501
 Kolster, H - 23.502
 Kompaniez, E - **23.406**
 Konar, Y - **61.21**
 Konen, CS - 16.432
 Konkle, T - **16.431**, 16.450, 23.456,
 62.16, 63.404
 Koopman, S - 36.530, **36.532**
 Kosovicheva, A - 26.545
 Kosovicheva, AA - **36.550**
 Kountouriotis, G - **53.501**, 53.520
 Kourkoulou, A - 41.15
 Kourtev, H - 23.424, 23.425, 23.428
 Kourtzi, Z - 36.528, 53.452, 63.438
 Kovács, I - 26.418
 Kowler, E - 16.411
 Kramer, A - 16.518, 53.307, 53.308,
 56.550
 Krause, B - **26.329**
 Krauzlis, R - **32.21**, 51.22
 Krauzlis, RJ - 26.514
 Kravitz, D - 16.423, 16.424, **25.16**,
 41.16, 56.449
 Kreager, R - 33.514
 Kreiman, G - 16.437, **31.26**, 56.516
 Kreindel, E - **63.428**
 Krekelberg, B - 26.512, 33.552,
 36.542
 Kriegeskorte, N - 25.23
 Kristjansson, A - **53.312**
 Krogh, L - 33.312
 Krummenacher, J - **26.442**, 56.405
 Kuai, S - **36.528**, 53.452
 Kuang, X - **23.318**
 Kubodera, T - 26.332
 Kucyi, A - 26.321
 Kuegel, A - 23.425
 Kuhl, B - **34.24**
 Kumada, T - 63.410
 Kumbhani, RD - **36.539**
 KURIBAYASHI, D - **43.413**
 Kuriki, I - 26.312, 36.447
 Kustner, LV - 36.511
 Kuta, E - 33.513
 Kuveldina, M - **16.521**, 16.522
 Kveraga, K - **33.451**
 Kvissberg, M - 16.412
 Kwon, M - 16.413, **22.12**
- Kwon, O - **36.513**
 Kwon, T - **56.426**
 Kyllingsbæk, S - **21.27**, 36.452
- L**
- LaBar, KS - 56.411
 Lachat, F - 33.423
 Lacquaniti, F - 33.548, 61.16
 Lacroix, M - 36.546
 Lages, M - **36.324**
 Lagos, A - 33.440
 Laguesse, R - **43.436**
 Lähde, M - 63.401
 Lai, A - 33.545
 Lai, M - **33.414**, 43.426
 Laidlaw, K - **43.439**
 Lam, D - **43.410**
 Lamy, D - 33.458, 43.322, **53.444**
 Lanagan-Leitzel, LK - **56.410**
 Landau, A - 26.545, **32.24**
 Landy, M - **33.439**
 Landy, MS - 26.421, 26.550
 Langlois, T - 36.312
 Lankheet, M - 26.513
 Lanyon, L - 63.432, 63.434
 Lao, J - 56.303, **56.308**
 Lappe, M - 23.505, **36.408**
 Larsen, S - **56.545**
 Larson, A - **33.452**
 LASSALLE, A - **33.403**
 Lassonde, M - **63.325**
 Latecki, LJ - 56.427
 Lau, C - **36.315**
 Lau, H - 16.427, 36.454
 Lavell, C - 43.303, **43.304**
 Lavie, N - 54.26
 Lawlor, M - 53.401
 Lawrence, J - 53.521
 Lawton, R - 23.551
 Laycock, R - 56.541
 Layton, O - 26.551, **33.527**
 Le Dantec, C - **53.451**
 Leavitt, M - 23.444
 Leber, A - 33.513, 33.515
 Lebrecht, S - **56.530**
 Lechak, J - **33.515**
 Ledgeway, T - **31.17**, 33.519, 56.549
 Lee, AL - **31.15**
 Lee, B - 42.15
 Lee, J - 26.511, **33.317**
 Lee, K - 24.16
 Lee, RK - **56.306**
 Lee, S - **16.424**
 Lee, Y - 23.421
 Lee, YL - **63.446**
 Leeds, D - **56.531**
 Leekam, S - 41.15
 Lefèvre, P - 23.534
 Legault, I - **23.436**
 Legge, G - 26.322
 Legge, GE - 53.514
 Lehky, S - **23.408**
 Leigh, RJ - 23.304
 Lengyel, M - 26.503, 42.26
 Leonard, CJ - **43.320**
 Leonard, Z - 33.517
 Leone, L - **63.448**
 Lepage, M - 56.517
- Lepore, F - 63.325
 Lescroart, M - 41.17
 Lescroart, MD - **31.21**
 Lesmes, LA - **53.552**
 Lessard, DA - **53.508**
 Lester, BD - 34.12
 Leung, S - 56.547
 Lev, M - **63.327**
 Léveillé, J - **33.531**
 Levi, D - 22.26, 33.332, 36.501, **41.12**
 Levillain, F - **63.308**
 Levin, D - 26.452, 43.325, **43.408**
 Levine, M - **23.431**, 56.302
 Levinthal, B - **53.305**, 53.410
 Levitin, DJ - 36.312
 Lewis, D - **36.509**
 Lewis, T - 33.318
 LEWIS, T - 33.328
 Lewis, TL - 26.410
 Leyrer, M - **56.423**
 Leyssen, M - 56.420
 Li, A - 23.416
 Li, C - 26.451
 Li, J - 63.316
 Li, K - 32.25
 Li, L - 26.415, 53.510, 53.512, **53.518**
 Li, M - **16.436**
 Li, Q - **26.434**
 Li, S - 26.502
 Li, W - **43.424**
 Li, X - 23.423, **63.445**
 Li, Y - 23.422, 26.438, 36.403, 56.426,
 56.427, 63.447
 Li, Z - 23.547, 56.430
 Liang, S - 43.432
 Liao, H - **33.505**
 Liberman, A - 23.541
 Liebenson, P - 33.440
 Lieby, P - 36.403
 Likova, L - **42.27**
 Lin, J - **26.435**
 Lin, ST - **43.415**
 Lin, Y - 33.323
 Lin, Z - **31.16**
 Linares, D - **34.15**
 Lindenbaum, M - 62.23
 Lindner, A - 55.14
 Lindsey, D - **42.17**
 Ling, S - 42.21
 Ling, Y - 36.307, 41.15
 Linhares, J - 26.307
 Linkenauger, SA - 56.423, **56.424**
 Lipp, OV - 16.525
 Lisitsyn, D - 26.503, 43.433, 63.306
 List, A - **23.402**
 Lister, J - 36.448
 Liston, D - **23.306**
 Listorti, C - **23.320**
 Little, A - 43.434
 Liu, C - 36.514, 42.22, **42.23**
 Liu, J - 36.503, **42.24**, 43.442
 Liu, L - 56.548
 Liu, N - 36.403
 Liu, P - 43.427
 Liu, T - 23.453, **26.322**, 36.450, 51.25
 Liu, Y - **51.12**
 Liu, Z - 25.22, 33.538
 Liverence, B - **41.23**
 Livingood, J - 33.319
- Livingstone, M - **36.515**, 36.527
 Lleras, A - 41.26, 53.329
 Llerena Law, C - **16.542**
 Lockheed, K - 23.545
 Loeper-Jeny, C - 16.514
 Loffler, G - 43.302
 Logan, A - 63.455
 Lohrenz, MC - 23.325
 Loomis, J - 36.408
 López-Moliner, J - 23.550
 Loschky, L - 33.452
 Lossin, F - 36.534
 Lourenco, T - 56.541
 Love, S - **36.429**
 Lovejoy, L - 51.22
 Lovell, PG - **51.14**
 Loveridge, C - 41.15
 Low, W - 63.413
 Lu, H - 23.517, 26.520, 31.15
 Lu, Z - 23.448, 26.501, 33.327,
 36.453, 36.503, 36.526, 41.22,
 42.24, 63.412, 63.440
 Lucey, S - 33.427
 Luck, S - 33.510, 53.438, 63.405
 Luck, SJ - 43.320
 Ludwig, C - **26.548**, 33.304
 Lugtigheid, AJ - **43.417**
 Lunghi, C - **52.15**
 Lupyan, G - 36.328, **56.523**
 Luria, R - **16.451**
 Lustig, AG - **26.436**
 Lyu, S - 36.549, **63.440**
- M**
- M. DeGutis, J - 23.543
 Ma-Wyatt, A - **23.549**, 53.529, 55.13
 Ma, L - 16.433
 MacDonald III, A - 26.418
 MacEvoy, S - 56.436
 Machilsen, B - 53.408
 Machizawa, M - **63.416**
 Mack, A - 16.519, 23.457
 Mack, M - **56.524**
 Mack, ML - 56.305
 Mack, S - 23.323
 Mack, SC - **51.26**
 MacKenzie, K - 56.542
 MacKenzie, KJ - **24.14**, **43.416**
 Macknik, S - 16.403, 63.313
 Macknik, SL - 23.304, 33.556
 MacLean, MH - **36.441**
 MacLeod, D - 26.301, 42.13
 MacNamara, A - 56.417
 MacNeilage, P - **36.538**
 Madsen, J - 16.437, 31.26, 56.516
 Maehara, G - **36.543**
 Magis-Weinberg, L - 53.533
 Mahler, M - 23.511
 Maji, S - 25.21
 Makovski, T - 53.314
 Malcolm, GL - **56.439**
 Malek, N - **23.409**
 Malik, J - 25.21, 35.15
 Maloney, L - **61.26**
 Maloney, LT - 55.12, 63.319
 Mamassian, P - 23.401, **26.504**,
 32.14, 36.423, 36.545, 43.419
 Manahilov, V - 63.455

- Manassi, M - **26.531**
Mance, I - **23.453**
Maniscalco, B - **36.454**
Mann, D - **36.428**
Manoach, D - 63.432
Mansouri, B - 33.330
Marcos, S - 23.406
Mareschal, D - 32.13, 36.432, 56.509
Marín-Franch, I - 26.314
Marino, C - 41.14
Marinovic, W - **43.328**
Marion, R - 32.25
Marlow, P - 21.11, 63.443
Marois, R - 26.423
Marotta, J - **23.545**
Marotta, JJ - 33.436
Marque, P - 56.412
Marques, JP - 32.16
Marriott, K - 23.307
Martin, A - **16.506**, 41.16
Martin, T - **43.324**
Martinez-Conde, S - 16.403, 23.304, 33.556, 63.313
Martinez-Trujillo, J - 23.409, **23.444**, 34.25
Maruya, K - 21.12, 34.15, **61.15**
Masakura, Y - 33.555
Mascheretti, S - 41.14
Masson, G - 36.537
Masson, GS - 36.545, 51.21
Massot, C - **23.415**
Masuda, O - **26.307**
Mathewson, KE - **36.440**
Mathey, MA - 23.311
Mathison, J - **23.536**, 33.315, 56.327
Mathôt, S - **24.26**
Mathuranath, P - 43.303
Matin, L - 43.424
Matsukura, M - **16.416**
Matsumiya, K - 26.312, 33.530, 36.447
Mattaloni, E - 56.519
Mattar, MG - **53.533**
Mattarella-Micke, A - 63.415
Matthews, N - **53.325**, 53.455
Matthis, J - 25.13, **53.519**, 55.16
Matthis, JS - 53.502
Mattingley, J - 21.26, 33.405, 53.315
Mattingley, JB - 25.15
Mauger, E - 56.315
Maurer, D - 26.410, 33.318, 33.420, 56.323, 56.324
MAURER, D - 33.328
Maus, G - **63.316**, 63.317
Maus, GW - 36.550
Maxfield, N - 36.448
May, K - **26.549**
May, KA - 43.420
Maybery, M - 56.508
Mayer, KM - 16.513
Mazzilli, G - **23.418**
McAdam, T - 55.11, 56.425
McCann, B - **35.14**
McCarley, J - 16.518, 33.550, 56.550
McCarthy, C - 36.403
McCarthy, JD - **43.314**
McCleery, JP - 62.22
McClelland, JL - 56.521
McCollough, A - **23.454**
McCourt, E - 54.28
McCourt, M - 63.448
McCourt, ME - 16.526, 53.313, 53.428
McDermott, KC - 16.540, 36.443
McDevitt, E - 36.518, 53.527
McGlinchey, R - 33.431
McGraw, P - 31.17, 41.11
McKeefry, D - 23.455
McKendrick, A - 63.449, **63.450**
McKendrick, AM - 56.503
McKendrick, R - 36.505
McKone, E - 33.411, **43.431**
McLean, A - 55.11
McLean, A - 56.425
McMains, S - **16.507**
McOwan, P - 23.529
McQuade, M - 33.452
McWilliams, E - 53.432
Medeiros-Ward, N - **23.432**
Medford, K - **53.420**
Mednick, S - 36.518
Mednick, SC - **53.527**
Mei, M - 42.27
Meinhardt, G - 26.409
Meixner, T - 61.27
Mejia, N - 33.440
Melnick, M - **26.506**
Melton, E - 53.451
Mendoza, D - **34.25**
Meng, G - **23.403**, 53.441
Meng, M - 16.534, 33.401, 53.524, 61.23
Menmeer, T - 53.447
Merat, N - 53.501
Mercado, R - 23.543
Mercado, RJ - **56.307**
Mestre, D - 25.14
Metta, G - 43.409
Mettler, E - **23.435**
Mevorach, C - **53.306**
Meyer, J - **22.25**
Meyerhoff, H - 53.428
Meyerhoff, HS - **23.437**
Meza, C - 43.323
Mezer, A - 26.544
Mian, J - 33.402, **56.322**
Michel, M - **54.17**
Miconi, T - **41.27**
Miellet, S - 56.308, **61.25**
Mier, D - 56.311, **56.312**, 56.510
Migliaccio, R - 16.514
Mihashi, T - **26.319**
Mikellidou, K - **26.530**
Milberg, W - 33.431
Miller, C - 26.329
Millin, R - **26.525**
Mills, M - 16.410
Minakata, K - **53.421**
Mingolla, E - 16.527, 26.510, 26.551, 33.527, 36.455, 36.547, 56.407
Mirpour, K - **56.414**, 56.415
Mishkin, M - 25.16
Mital, PK - 16.407
Mitchell, D - 34.23, **56.447**
Mitchell, DJ - 32.26
Mitroff, S - 16.541
Mitroff, SR - 56.411, 63.431
Mizokami, Y - **36.305**
Moher, J - **62.26**
Moher, M - **16.445**
Mohler, B - 56.423
Mohler, BJ - 33.426, 56.424
Mojica, A - **43.310**, 43.315
Mojica, AJ - 26.441
Mokeychev, A - **26.437**
Molnar, D - 24.17
Mon-Williams, M - 23.312, 23.551, 33.442, 33.443, 53.520
Mon-Williams, PM - 36.420
Mondloch, C - 33.402, 56.322, 56.329
Monnot, J - 56.317
Montagnini, A - 36.537, 36.545, 51.21
Montaser-Kouhsari, L - 43.427
Montreuil, T - 56.517
Moore, C - 33.303
Moore, CM - 56.555
Moore, T - 24.24
Morand, SM - **16.419**
Mordkoff, JT - 53.320
Morgan, L - **56.435**
Morgan, M - 34.16, **53.536**, 54.18
Morgan, MJ - 53.413
Morgenstern, Y - **42.14**
Morizot, F - 56.315
Moro, SS - **36.434**
Morrone, C - 24.21, 24.22, 52.15
Morrone, MC - 24.25, **41.14**, 53.302
Morvan, C - **24.23**
Moscatelli, A - 33.548, **61.16**
Mossbridge, J - **21.22**, 32.12
Most, S - 54.25
Most, SB - **16.522**, 63.427
Mote, J - 33.451
Motoyoshi, I - 16.511, 21.12, **26.534**, 34.15
Mould, MS - **43.406**
Mouri, C - **36.507**
Movshon, JA - 36.539, 36.548, 54.13
Mruczek, RE - **16.432**
Muckli, L - 32.17, 56.303
Mudrik, L - **33.458**
Muggleton, N - 36.522
Mulla, A - 23.308, 33.434
Müller, HJ - 53.439, 53.445, 56.405
Mulligan, JB - **43.404**
Mullin, C - **16.440**
Munn, JC - 33.454
Munneke, J - **23.443**
Munoz, D - 16.516, 23.301, 63.454
Murakami, I - 16.529, 31.13, 36.554, 55.23
MURAKOSHI, T - **16.523**
Murphy, AP - **63.436**
Murray-Kolb, L - 16.510
Murray, RF - 21.14, 42.14
Murray, S - 16.515, 26.435, 53.419
Murray, SO - 53.302
Muryy, AA - **63.437**
Musel, B - **56.452**
Muthukumaraswamy, S - 36.535
Myers, E - 33.531
-
- N**
Nadasdy, Z - **23.410**
Naderiyanha, A - 52.14
Nador, J - 61.11
Nagai, T - **36.540**, 53.456
NAGASAKA, Y - 23.501
Naito, S - 26.413, 26.419
Najafian Jazi, A - **63.313**
Najima, R - 23.448, **63.412**
Nakajima, Y - 26.309
Nakamura, N - 26.319
Nakamura, Y - **53.456**
Nakashima, R - **26.445**
Nakato, E - **56.321**
Nakauchi, S - 36.540, 53.456
Nakayama, K - 23.536, 23.542, 23.543, 33.422, 33.431, 63.404
Nalbandian, A - 53.521
Nandy, AS - 16.413, 22.12, **26.539**, 53.550
Náñez, J - 26.505
Narain, D - **23.552**
Narang, S - 26.430, 33.448
Narasimhan, S - **33.331**
Nardini, M - **32.13**, 36.432, 56.509
Näsänen, R - 53.545
Nascimento, S - **26.304**, 26.307
Nascimento, SM - 26.314
Nasr, S - **35.23**
Nath, A - 36.424
Natu, V - 33.425
Nawrot, E - **33.319**
Nawrot, M - 33.319, **33.517**, 33.537
Nefs, H - **56.421**
Neider, M - 16.518, 53.308, 56.403, **56.550**
Neill, WT - **26.438**
Nelli, FD - **36.517**
Nemes, V - **23.455**
Nemrodov, D - **43.449**
Nestor, A - **35.25**
Neumann, H - 33.528, 36.502, 36.547
New, J - 53.425, **56.302**
Newling, K - 43.445
Ngo, N - 36.505
Nguyen, B - **53.511**
Nguyen, M - 23.541
Ni, R - 22.27, 53.509, 53.511
Nicholas, S - 42.27
Niederprüm, K - 63.429
Niehorster, DC - **53.510**
Niemeier, M - 36.444
Nili, H - 25.23
Ning, A - 23.547
Nishida, S - **21.12**, 33.541, 34.15, 61.15
Nishina, S - **26.505**
Nizam, AJ - 53.542
Noda, M - 63.458
Noonan, S - 16.503, 26.432
Noori, N - **16.408**
Norcia, A - **24.13**, 24.15, 43.329, 55.21
Nori, F - 43.409
Norman, J - **33.520**
Norman, JF - **63.451**
Norman, K - 34.22
Northway, N - 63.455
Noudoost, B - 24.24
Noyce, A - **16.509**

- Nuthmann, A - 56.439
 Nwosu, C - 63.430
 Nyström, M - 43.402, 43.403
-
- O**
- O'Brien, J - **36.448**
 O'Neil, SF - **43.435**
 O'Reilly, R - 16.439
 O'Toole, A - **33.425**, 56.330
 Oakley, JP - 43.406
 Obinata, G - 36.531
 Odic, D - 16.447, **36.510**
 Ogiya, M - 33.530
 Ögmen, H - 22.22
 Ogmen, H - **34.17**
 Olin, S - 16.538
 Oliva, A - 16.431, 16.442, 16.450, 31.22, 62.16
 Olivers, C - **26.439**, 33.511
 Olivers, CN - 26.429
 Olk, B - **43.411**
 Olkkonen, M - **21.13**
 Olman, C - 26.408, **54.14**
 Olzak, L - **26.524**, 53.404
 Olzak, LA - 53.403
 Ong, WS - **23.519**
 Ono, K - **23.515**
 Ontiveros, Z - **33.440**
 Ooi, TL - **26.412**
 Optican, L - 36.529
 Or, CC - **33.421**
 Orbach, HS - 43.302
 Orban, G - 23.502, 33.435
 Orbán, G - 42.26
 Oriet, C - 53.534
 Orsten, K - **53.443**
 Ortega, L - 32.12, **33.546**, 63.430
 Oruc, I - 33.414, **43.450**
 Oruç, I - 43.426, 43.428
 OSADA, Y - 16.523, 23.501, 36.435, 43.413
 Osman, M - 16.406
 Ostendorf, F - 16.414
 Otero-Millan, J - 16.403, **23.304**, 63.313
 Otsuka, Y - 33.320, 56.320
 Otto, T - 22.22
 Otto, TU - **32.14**
 Ouhnana, M - **53.413**
 Overgaard, M - 52.17
 Owen, A - 36.307
 Owens, DA - **53.521**
 Owens, R - **26.528**
-
- P**
- Pachai, MV - **43.438**
 Paffen, C - 36.318, **36.322**
 Pailian, H - **63.414**
 Painter, D - **21.26**
 Palanica, A - **23.328**
 Palermo, R - **23.537**
 Pallett, P - **33.401**
 Palmer, E - 36.531, **53.440**
 Palmer, J - 56.555
 Palmer, SE - 36.309, 36.311, **36.312**, 36.313, 36.315
 Palmeri, T - 33.416, 56.518, 56.524
 Palmeri, TJ - 56.305
 Palomares, M - 16.448, 24.13, 24.15, 53.538, **53.539**, 56.502
 Pan, JS - **33.441**, 33.442
 Pan, Y - 26.401, **26.411**
 Pancaroglu, R - **23.538**, 43.428
 Panichi, M - **24.21**
 Panis, S - 56.526
 Pannasch, S - **63.310**
 Pantazis, D - 16.426
 Pantelis, P - **63.314**
 Papatomas, T - **23.417**
 Papenmeier, F - 23.437, 53.428
 Papper, M - 56.552
 Parade, M - **53.502**
 Pardo-Vazquez, JL - 33.556
 Paré, DE - 16.420
 Park, S - **53.532**, **62.16**
 Park, SH - 23.447, 26.443
 Park, WJ - **33.457**
 Parkinson, J - **23.506**
 Parkinson, L - 33.415
 Parks, N - **53.307**
 Parlangeli, O - 26.414
 Parr, L - **43.434**, 52.27
 Parraga, CA - **26.306**, 36.307
 Parrott, S - **53.422**
 Parvizi, J - 54.11
 Pascual-Leone, A - 36.415
 Patel, K - 24.17
 Patel, MN - **26.410**
 Patel, S - 22.15
 Patten, ML - **63.439**
 Patterson, MD - **63.413**
 Paz, N - 56.544
 Pearson, J - 36.509, 63.408
 Pearson, PM - 33.330
 Pedersen, L - 56.507
 Pedersini, R - **26.508**
 Peelen, MV - 62.11
 Pegors, T - **56.446**
 Peirce, J - 26.515
 Peirce, JW - 26.406
 Peli, E - 26.537, 36.525
 Pelleg, M - 35.22
 Pelli, D - **33.332**
 Pelli, DG - 22.14, 31.27, 32.15
 Pellicano, E - 56.509
 Perani, D - 41.14
 Pereira, E - **23.321**
 Perera, D - 23.524
 Perez, C - 56.450
 Perini, F - **54.15**
 Perler, B - 23.544
 Pernet, C - 36.449, 36.451
 Perrett, D - **52.23**
 Perrinet, LU - 36.545
 Perrone, JA - **26.514**
 Perry, J - 35.12
 Persike, M - **26.409**
 Persuh, M - 26.449, **33.551**
 Petersen, A - **53.328**, 56.507
 Peterson, M - **26.431**, 43.310, 43.315
 Peterson, MA - 26.441, 43.454
 Peterson, MF - **61.24**
 Peterzell, D - **26.328**
 Petrini, K - 36.429
 Petrov, A - 22.25, 43.401
 Petrov, AA - 31.24, **42.25**
 Petrov, Y - **61.11**
 Pettypiece, C - 56.425
 Peyrin, C - 56.450, 56.451, 56.452
 Peyton, MS - 56.431
 Pfister, R - **53.446**
 Phan, M - **22.27**
 Pharchi, M - 56.501
 Phelps, EA - 36.319
 Philbeck, J - 56.428
 Phillip, G - 52.11
 Phillips, F - 23.414, 23.518, **51.16**, 55.16
 Phillips, J - 33.425
 Piazza, E - **23.407**, 23.412, 56.419
 Pickup, L - **56.432**
 Pierce, L - 25.26
 Pierce, M - 52.24
 Pierce, R - **63.456**
 Pilz, KS - **21.21**, 63.452
 Pisella, L - 36.417
 Pitcher, D - 23.539, **43.451**
 Pitts, CH - **16.448**, 53.539
 Piwek, L - 23.504
 Pizlo, Z - 23.422, 56.426, 56.427, 63.447
 Platt, M - 23.536
 Plaut, D - 35.25
 Ploran, E - 23.531
 Pobric, G - **56.413**
 Poeppel, D - 32.15
 Poggio, T - 16.438
 Pola, J - **33.309**
 Polat, U - 63.327
 Polczyk-Przybyla, JA - 53.547
 Poletti, M - **23.316**, 23.319, 23.320
 Pollatsek, A - 23.324
 Pollick, F - **23.504**
 Pollick, FE - 36.429
 Pollmann, S - 36.436
 Poltoratski, S - 23.541, **53.541**
 Pomerantz, J - **43.318**, 53.409, 53.412
 Pomerantz, JR - 53.443
 Poncet, M - **56.512**
 Pont, S - **26.302**
 Popivanov, I - 23.502
 Popovic, M - **26.503**
 Porcheron, A - **56.315**
 Portillo, M - **53.412**
 Portillo, MC - 53.443
 Possidente, P - **55.16**
 Postma, A - 56.520
 Potter, M - **54.28**, 63.406
 Poulter, D - **33.321**, 36.410, 56.505
 Powell, R - 33.454
 Pradat-Diehl, P - 16.514
 Pratt, J - 26.448, 33.437, 36.413, 53.304, 53.326
 Preston, T - 56.416, **62.17**
 Price, K - **56.402**
 Prime, SL - **33.436**
 Prins, N - **26.521**
 Prinz, W - 23.506
 Prinzmetal, W - **26.427**
 Proffitt, D - 36.412, 36.421
 Punzi, G - 63.322, 63.323
 Purcell, B - 36.439
 Purcell, C - 33.321, **56.505**
 Puri, A - 23.540
 Purushothaman, G - **32.25**
 Putzeys, T - 26.542, 53.408
 Pyles, J - 56.531
 Pyles, JA - **43.452**
 Pylyshyn, Z - 23.424, 23.425, 36.446, 53.327
 Pynn, L - 26.321
-
- Q**
- Qian, J - 61.11
 Qian, S - 36.413
 Qian, W - **54.22**
 Quadflieg, S - **23.535**
 Quaia, C - 36.529
 Quetard, B - 23.309
-
- R**
- Radonjic, A - 16.528
 Radonjić, A - **42.12**
 Radulescu, P - **33.437**
 Rae-Hodgson, R - 63.301
 Rafal, RD - 23.303
 Ragland, D - 26.418
 Raio, C - 36.319
 Raj, A - **53.411**, 53.537
 Rajsic, J - **53.319**
 Ramachandran, V - 23.423, 26.329, **36.317**
 Ramon, M - **43.442**
 RANA, KD - 63.304
 Rand, K - **56.433**
 Rangelov, D - 53.445
 Raninen, A - **53.545**
 Rappaport, SJ - **26.440**
 Ratcliff, R - 42.25
 Rathakrishnan, V - 23.424, 23.425
 Ratzlaff, M - 33.517
 Raudies, F - **36.547**
 Rauschecker, AM - 54.11
 Raw, R - 53.520
 Re, D - 52.23
 Read, J - 52.13
 Read, JC - 26.523
 Reavis, EA - 16.504, 26.308, **53.442**
 Reddy, L - 56.512
 Reed-Jones, J - **56.558**
 Reed-Jones, R - 56.558
 Reed, C - **23.530**
 Reed, S - **63.320**
 Rees, G - 23.508, 24.11, 36.522, 52.16, 52.17, 52.21, 53.528, 53.548
 Reeves, A - **26.320**
 Reichle, E - 23.324
 Reichow, A - 43.425
 Reijnen, E - **56.405**
 Remington, R - 53.315
 Remus, D - 43.448
 Rémy, F - 56.513
 Renninger, L - 23.315, 23.549, **55.13**
 Rensink, R - **53.414**
 Ress, D - 23.305, **54.12**
 Reynolds, JH - 26.539
 Rezlescu, C - 23.539
 Rhee, J - **23.456**
 Rhodes, G - 23.522, 33.413
 Rich, A - 53.430, 53.448
 Richard, B - **35.16**

- Richler, JJ - 56.305
 Riddle, M - 16.531
 Riddoch, MJ - 26.440
 Rider, D - 61.14
 Riegal, Y - 53.405
 Rieiro, H - **33.556**
 Ringbauer, S - **36.502**
 Ringstad, P - 63.314
 Rio, KW - **53.503**
 Risko, E - 16.402, 43.439
 Rivolta, D - 23.537
 Ro, T - 26.449, 33.551, 36.440
 Robbins, R - **23.524**, 33.427
 Robertson, C - **41.16**
 Robertson, E - 36.415
 Robertson, L - 23.528, 23.540, 36.314, 53.301
 Robertson, LC - 53.544
 Robinson, A - **26.301**
 Roca-Vila, J - 26.306, **36.307**
 Rocchi, F - **33.519**
 Roehrbein, F - **16.415**
 Rogers, B - **33.532**
 Roggeveen, AB - 21.21
 Rokem, A - 26.427, **36.518**
 Rolfs, M - **24.27**, 63.318
 Roller, B - **26.441**
 Roncato, S - 26.414
 Roper, ZJ - **53.320**
 Roseboom, W - **55.17**, 61.17
 Rosen, S - **22.14**
 Rosenbaum, D - 36.421
 Rosenberg, M - 16.503, **26.432**
 Rosenberg, Y - 33.447
 Rosenholtz, R - 21.17, 53.411, 53.537
 Rosenthal, M - 24.17
 Roskies, A - 36.414
 Ross, D - **33.416**
 Ross, M - **63.432**
 Rossion, B - 23.534, 23.535, 24.15, 43.436, 43.440, 43.441, 43.442, **43.443**, 61.22
 Rossit, S - 33.432, **55.11**
 Rossiter, A - **23.551**
 Roth, EJ - **36.443**
 Roth, J - 54.21
 Roth, O - **16.447**
 Rothkirch, M - **16.414**, 63.433
 Rothkopf, C - 36.411
 Rotshtein, P - 16.502
 Roudaia, E - **63.452**
 Rousselet, G - 16.434, 36.449, **36.451**
 Rowe, J - 35.24
 Rowe, JB - 25.23
 Rubin, G - 33.326
 Rucci, M - 23.316, 23.318, 23.319, 23.320, 36.401
 Rudd, ME - **16.535**
 Ruijie, W - 43.432
 Runeson, E - **16.515**
 Rushton, S - **36.402**
 Rushton, SK - 23.554, 25.11, 33.525, 33.526
 Russell, R - 56.301, 56.315
 Rutherford, M - 24.12
- S**
 Saarinen, J - 63.401
- Sadeh, B - **35.22**
 Saeb, S - **23.313**
 Saegusa, C - **56.313**
 Saenz, M - **32.16**
 Said, CP - 16.501
 Saiki, J - 26.434, **36.316**, 56.529
 Saint-Aubert, L - **56.513**
 Sakai, K - 16.435
 Sakamoto, S - 26.332
 Sakata, K - 26.319
 Sakurai, K - **26.332**
 Saleem, K - 25.16
 Salmela, V - **63.401**
 Salvagio, E - 26.441, **43.315**
 Sampath, V - 56.328
 Sanbonmatsu, K - 16.441
 Sandberg, K - **52.17**
 Sandini, G - 26.324, 43.409
 Sanghvi, S - 53.544
 Sanik, K - 63.314
 Sanocki, T - 54.24, **56.444**, 62.24
 Sapir, A - 26.420
 Saragih, J - 33.427
 Sasaki, Y - 26.505, 32.27, 42.22, 42.23
 Sato-Reinhold, J - **36.442**, 56.418
 Sato, H - 56.551
 Sato, M - 43.421
 Sato, T - 23.434, 23.515, **26.309**
 Saunders, DR - **23.507**
 Saunders, J - **23.421**, 63.446
 Savatovsky, J - 56.450
 Sawada, T - 23.422, 56.426, 56.427, **63.447**
 Sawaki, R - **33.510**
 Sawayama, M - **16.530**
 Sawides, L - 23.406
 Saxe, R - 43.451
 Saygin, A - 53.433
 Saygin, AP - 23.508, 26.428, **55.25**
 Sayim, B - 26.531, **53.553**
 Saylor, M - 43.408
 Scalf, P - **56.556**
 Scarfe, P - **36.551**
 Schaal, B - 56.317
 Schade, T - 43.302
 Schall, J - 36.439
 Schallmo, M - **26.408**
 Schapiro, AC - **36.511**
 Scharff, A - **56.555**
 Schiller, P - **43.316**
 Schiltz, C - 43.430, 43.453
 Schindler, K - 33.410
 Schirillo, J - **16.531**
 Schlegel, A - **36.414**
 Schloss, KB - **36.309**, 36.312, 36.313, 36.315
 Schluppeck, D - 26.515
 Schmack, K - 36.546, **63.433**
 Schmidt, F - **53.418**
 Schmidt, J - **56.417**
 Schmidt, T - **26.407**, 53.418, 63.429
 Schnebelen, W - 31.27
 Schneider, K - 26.518, 33.324
 Schneider, W - 23.314, 43.452
 Schneiderman, M - 23.444
 Schofield, A - 23.405
 Schofield, AJ - 23.418, 53.453
 Scholl, B - 41.23, 53.425
- Scholl, BJ - 53.540
 Schöner, G - 33.520
 Schönhammer, J - **33.512**, 53.322
 Schor, C - 16.539, 33.310
 Schor, CM - 61.13
 Schrater, P - 26.507, **32.11**
 Schrater, PR - 36.504
 Schreij, D - 26.439, **33.511**
 Schroeder, J - **16.541**
 Schultz, J - **23.503**, 23.527, 33.409
 Schütz, A - 36.536
 Schütz, AC - **33.544**, 36.534
 Schwan, S - 23.326
 Schwartz, O - 16.415
 Schwarzbach, J - 54.15
 Schwarzkopf, D - 24.11
 Schwarzkopf, DS - **53.528**, 53.548
 Schweinhart, AM - **26.540**
 Schyns, P - 52.22
 Schyns, PG - 56.439, 61.25
 Scifo, P - 41.14
 Scilipoti, E - **16.543**
 Scimeca, J - 53.305, 54.21
 Sciutti, A - 26.324, **43.409**
 Scofield, I - **53.429**
 Scolari, M - **21.23**
 Scott, L - 25.26
 Scott, LS - 56.318
 Seckel, E - **23.423**, 26.329, 36.317
 Sederberg, P - 34.22, 43.401
 Sederberg, PB - 56.515
 Seegmiller, J - 23.432
 Seibert, D - 56.531
 Seiffert, AE - 23.427, 23.433, **23.438**, 23.439
 Seitz, A - 36.516, 53.451
 Sekuler, AB - 21.21, 23.445, 26.527, 36.433, 43.438, 56.511, 61.21, 63.452, 63.453
 Sekuler, R - 16.509, 23.445
 Sekunova, A - 23.538, **33.415**, 56.533
 Selden, D - 63.310
 Self, E - **33.553**, 53.429, 56.544
 Selig, G - **43.433**
 Semmelmann, K - 56.310
 Seo, KB - 23.447, 26.443
 Serences, J - 21.23, 26.450, 36.519
 Seror, G - 26.438
 Serra, A - 23.304
 Serrano-Pedraza, I - **26.523**
 Serre, T - 16.438, 43.422, 53.406, 56.516, 56.546
 Seydell, A - 26.407
 Sha, L - **53.524**
 Shachar, M - 33.447
 Shahani, U - 63.455
 Shalev, L - **56.501**
 Shamshiri, E - 63.328
 Shankey, J - 54.16
 Shapiro, A - **16.532**
 Shapley, R - 26.546
 Shapley, RM - 26.547
 Sharan, L - 21.17, **23.511**
 Shariat Torbaghan, S - **56.415**
 Sharman, R - **26.406**
 Sharp, M - **63.434**
 Sharpee, TO - 26.539
 Sheedy, J - 36.544
 Sheinberg, D - 56.401
- Sheinberg, DL - 56.530
 Sheldon, C - **56.533**
 Sheliga, B - **36.529**
 Shelton, A - 53.415
 Shen, J - **56.316**
 Sherman, A - **36.426**
 Sherman, AM - **56.406**
 Sherrington, R - 33.523
 Shevell, S - **16.533**, 31.25, 63.415
 Shi, Y - **23.422**, 56.426
 Shibata, K - **23.553**, 26.505
 Shibata, T - 43.418
 Shiffrar, M - 23.514, 63.312, 63.424, 63.426
 Shim, WM - 63.309
 Shimojo, E - **56.311**, 56.312
 Shimojo, S - 53.530, 56.311, 56.312, 56.313, 56.510
 Shimomura, T - **63.410**
 Shin, K - **53.554**
 Shinohara, K - **26.532**
 Shioiri, S - 26.312, **33.530**, 36.447
 Shirai, N - 33.320
 Shohara, R - 26.413, **26.419**
 Shomstein, S - 26.433, 26.448, 33.508, 63.435
 Shoener, C - **36.548**
 Short, L - **56.329**
 Shrimpton, S - 33.426
 Siagian, C - 36.404
 Siddiqui, A - **33.448**
 Siddiqui, AP - 26.430
 Siegel, M - 26.507
 Sihite, DN - 36.457
 Silbert, N - 52.26
 Silver, M - 23.407, 23.412, 26.427, **26.545**, 36.325, 36.518
 Silver, MA - 53.544
 Silverstein, S - 26.405
 Silverstein, SM - **26.418**
 Simmers, A - 31.17, 33.326, **33.329**
 Simon, MG - 56.515
 Simoncini, C - **36.545**
 Simons, D - 16.518, 56.527
 Sims, CR - **34.26**
 Singer, J - **16.437**, 31.26, 56.516
 Singh, K - 36.535
 Singh, M - 26.402, 26.403, 34.14, 43.306, 43.307, 43.308, 43.311, 51.15
 Singh, P - **36.409**
 Sinha, P - 23.520, 23.521, 26.323, 36.431, **41.13**, 43.407
 Sinnott-Armstrong, W - 36.414
 Sio, JL - **36.326**
 Sipe, G - 26.326
 Slesar, C - 16.519, **23.457**
 Sloper, J - 33.326
 Smeets, JB - 23.552
 Smilek, D - 61.27
 Smirl, J - 16.545
 Smith, AT - 33.523, 36.521, **55.24**
 Smith, E - 63.430
 Smith, F - **33.404**, 56.303
 Smith, FW - 32.17
 Smith, L - 16.404
 Smith, P - 53.538
 Smith, TJ - **16.407**
 Smuskowitz, L - 33.434

- Snapp-Childs, W - 33.429, **33.442**, 63.457
 Snow, J - **56.425**
 Snyder, JJ - **26.425**
 Sofer, I - **56.546**
 Sok, KW - 23.511
 Sokoliuk, R - **36.416**
 Sokumbi, D - 53.412
 Solomon, J - **34.16**
 Solomon, JA - 53.413
 Song, C - **24.11**, 53.528
 Song, J - **53.457**
 Song, S - 33.332
 Sørensen, TA - **43.327**
 Sosa, Y - **53.313**, 53.421
 Soto, F - **53.523**
 Soussignan, R - 56.317
 Sparapani, S - 36.553
 Sparck, E - 43.318
 Speck, O - 36.436, 36.523
 Spelke, E - 16.452
 Spencer, JM - **56.511**
 Sperring, M - 36.539
 Sperling, G - **36.549**, 63.440
 Spitschan, M - 43.420
 Sponheim, S - 26.408
 Srihasam, K - 36.515, **36.527**
 Srinivasan, R - 21.25
 St. Clair, R - **23.439**
 Stanton, H - 43.437
 Steel, W - 23.504
 Steeves, J - 16.440, 33.324
 Steeves, JK - 36.434
 Stefanucci, J - 56.429
 Stefanucci, JK - 53.508
 Stein, T - **36.320**
 Steinbach, MJ - 43.410
 Stemmler, T - 43.422
 Stepanov, V - **16.524**
 Stephen, I - 52.23
 Stephens, L - 33.454
 Sterling, C - 55.15
 Sterzer, P - 16.414, 36.320, **36.546**, 63.433
 Stewart, L - 52.21
 Stiels, M - 36.408
 Stienen, B - **33.410**
 Stigliani, A - **56.436**
 Stiles, J - 24.16
 Stjepanovic, D - **33.405**
 Stocker, AA - 31.12
 Stoffleth, D - 54.28
 Stojanoski, B - **36.444**
 Stolte, M - **54.26**
 Stone, L - 23.306
 Stoyanova, RS - **56.314**
 Strang, NC - 63.455
 Stransky, D - **63.442**
 Strauss, ED - **36.313**
 Strauss, M - 26.418
 Strayer, D - 23.432
 Strickland, B - **33.449**
 Stroman, P - 56.425
 Stromswold, K - **24.17**, 56.445
 Strong, E - **56.301**
 Strother, L - **43.303**, 43.304
 Stroud, M - **53.447**
 Stroyan, K - 33.517, **33.537**
 Stuit, S - **36.318**
 Stupina, A - 43.318, **53.409**
 Su, C - **35.11**
 Su, J - 33.419
 Su, X - 43.308
 Su, YR - 26.412
 Suchow, J - 16.429, **63.315**
 Sugarman, M - 53.420
 Sugovic, M - **56.434**
 Sullivan, B - **36.411**
 Sulman, N - **54.24**, 56.444
 Sun, H - **56.525**
 Sunny, MM - **33.506**
 Susilo, T - 33.411
 Suttle, LK - **53.522**
 Suzuki, H - 36.303
 Suzuki, S - 21.22, 23.402, 32.12, 33.546, 36.426, 56.402, 63.430
 Suzuki, Y - 26.332
 Swallow, K - **53.314**
 Sweeny, T - **55.26**
 Swisher, J - **42.21**
 Sy, J - **53.317**
 Sy, JL - 21.27, 36.442
 Symons, L - **16.538**
 Szinte, M - **33.306**
-
- T**
 Tadin, D - 26.327, 26.506, 26.517, 63.302
 Tahir, H - **16.539**
 Tai, Y - 36.544
 Tailor, V - 33.326
 Tajima, S - 36.303, 55.23
 Takahashi, E - 42.22
 Takahashi, T - 16.511
 Takeda, T - 16.511
 Takemura, H - **55.23**
 Takenaka, I - 56.551
 Tam, D - **53.410**
 Tamietto, M - **33.406**
 Tan, C - **16.438**
 Tan, H - 23.504
 Tan, Z - **26.520**
 Tanaka, J - 23.532, **25.26**, 61.27
 Tanaka, JT - 23.450
 Tanaka, JW - 52.24
 TANAKA, Y - 43.413
 Tao, G - **53.504**
 Tao, L - 36.526
 Tapia, E - **26.417**
 Tappen, MF - 31.23
 Tarampi, M - 56.433
 Tarampi, MR - 53.508, 56.431
 Tarita-Nistor, L - 43.410
 Tarr, M - 56.531
 Tarr, MJ - 36.520, 43.452, 56.530
 Tas, C - **33.303**
 Taubert, J - **52.27**
 Taya, S - **16.406**
 Taylor, C - **36.308**, 36.310
 te Pas, S - 23.420
 ten Oever, S - 43.453
 Tenenbaum, J - 33.534
 Teng, S - **36.425**
 Terao, M - 31.13
 Teves, J - **53.509**
 Thai, K - **53.450**
 Thaler, L - **36.418**
 Theeuwes, J - 23.301, 23.443, 24.26, **32.22**, 63.423
 Thengone, D - 26.541
 Theobald, S - 53.325
 Thesen, T - 16.427
 Thiebaut de Schotten, M - 16.514
 Thomas, A - 33.524
 Thomas, C - **16.423**, 41.16
 Thomas, J - **23.514**
 Thomas, L - **16.418**, 23.438
 Thomas, LE - 23.433
 Thomas, R - **36.432**
 Thompson, J - **23.531**
 Thompson, P - 26.530
 Thompson, TW - **23.440**
 Thompson, W - 56.429, 56.433
 Thompson, WB - 53.508
 Thornton, IM - **23.441**, 33.426
 Thorpe, S - 23.310
 Thorpe, SJ - 23.311, **34.27**
 Thurman, S - **23.509**
 Tibber, M - **53.535**, 54.18
 Tillman, KA - **31.27**
 Tillman, M - **33.417**
 Tjan, BS - **16.413**, 16.426, 22.12, 26.525, 53.546, 53.550, 53.554
 Tkaczyk, A - **43.323**
 Toba, MN - **16.514**
 Todd, J - 33.454, 51.16
 Todd, JT - 23.414, 31.24
 Todorov, A - 23.535, 52.21
 Todorovic, D - **23.419**
 Tokuda, S - **36.531**
 Tokunaga, R - 16.531, 26.312
 Töllner, T - **53.445**
 Tong, F - 42.16, 42.21
 Tong, J - 16.539, 33.310
 Tootell, R - 35.23
 Torfs, K - **56.526**
 Torralba, A - 16.442
 Toscani, M - **26.303**
 Toseeb, MU - **23.526**
 Tower-Richardi, S - **33.305**
 Townsend, J - 52.26
 Toyoshima, H - 53.407
 Tran, C - 56.544
 Travis, S - 21.26
 Tremblay, J - 63.325
 Tremblay, L - 23.548, **36.424**
 Triesch, J - 23.313
 Troje, N - **23.513**
 Troje, NF - 23.507
 Trommershaeuser, J - **53.529**
 Troncoso, XG - 23.304
 Trongnetrpanya, A - 16.427
 Tsai, Y - 42.23
 Tsai, Y - **41.25**, 53.306
 Tsang, T - 36.312
 Tschechne, S - **33.528**
 Tse, P - **26.424**, 36.414, 63.305
 Tse, PU - 16.504, 26.308, 36.550, 53.442, 62.12
 Tseng, C - 33.314, 33.322
 Tseng, P - **63.454**
 Tseng, Y - 26.451, **53.329**
 Tsirlin, I - **63.441**
 Tsoi, L - **36.530**, 36.532
 Tsotsos, LE - **63.453**
 Tsou, B - 26.333
- Tsubomi, H - **63.418**
 Tsui, GH - **33.314**, 33.322
 Tsuruhara, A - **33.320**
 Turk-Browne, NB - 16.501, 35.26, 36.505, 36.511, 53.522, **56.515**
 Turner, K - **53.423**
 Turret, J - 56.553
 Twarog, NR - **31.23**
 Twedt, E - **36.412**, 36.421
 Tyler, C - **51.11**
 Tyler, CW - 63.445
 Tyler, SC - **43.326**, 56.309
-
- U**
 Uchikawa, K - 26.311, 26.319, 26.532, 53.517
 Unuma, H - **43.301**
 Urgen, BA - **26.428**, 55.25
 Uruno, Y - 53.506
 Utz, S - **62.22**
-
- V**
 Vaina, L - 63.303
 VAINA, L - **63.304**
 Valadao, D - **53.323**
 Valero-Cabré, A - 36.445
 Valsecchi, M - 26.303, **33.547**, 56.438
 van Beers, RJ - 23.552
 Van Belle, G - **23.534**
 van Boxtel, J - **23.517**
 van der Burg, E - 32.22
 van der Kooij, K - **23.420**
 van der Linde, I - **16.443**
 van der Smagt, M - 36.318
 Van der Stigchel, S - 16.410, 36.322, 56.520
 van der Stigchel, S - **23.303**
 Van Der Zwaag, W - 32.16
 Van Doorn, A - 56.420
 Van Horn, NM - **31.24**, 42.25
 van Koningsbruggen, MG - 23.303
 van Lamsweerde, AE - **16.449**
 van Mierlo, CM - 63.437
 van Wessel, R - 26.513
 van Zon, J - 43.430
 Vancleef, K - **53.408**
 Vanduffel, W - 23.502
 Vangkilde, S - 53.328
 Vannasing, P - 63.325
 Vanni, M - 52.14
 Vanrell, M - 26.306
 VanRullen, R - 16.430, 26.519, 36.416, 36.437, 41.27, 56.412
 Varakin, DA - **56.437**
 Vatterrott, D - **33.507**
 Vayssière, N - 56.513
 Vaziri Pashkam, M - **51.24**
 Vecera, S - 33.507, 54.27
 Vecera, SP - 53.320
 Veenemans, A - **53.424**
 Velichkovsky, B - 63.310
 Venkatramanan, S - 16.510
 Verghese, P - **41.21**, 53.309
 Vernet, M - **36.415**
 Verosky, SC - **35.26**
 Verstraten, F - 36.318
 Verstraten, FA - 31.14

- Verstynen, TD - 43.452
Vessel, E - 33.312
Vetter, P - **32.17**
Vicente-Grabovetsky, A - **32.26**, 34.23
Vickery, T - **43.317**
Victor, J - **26.541**
Vida, M - **56.324**
Vienne, C - **43.419**
Vignal, C - 56.451
Vilis, T - 43.303, 43.304
Vingilis-Jaremko, L - **56.323**
Viret, A - 56.451
Visser, TA - 16.525
Viswanathan, J - **16.412**, 26.444, 63.432, 63.434
Vitu, F - 23.302, 23.310
Vizioli, L - 16.419, **56.303**, 56.308
Vlaskamp, B - 36.538
Vlassova, A - **63.408**
Vo, M - **62.27**
Vo, V - **23.547**
Vogel, E - 16.451, 23.454
Vogel, EK - 23.452, 63.418
Vogels, R - 23.502
Volcic, R - **51.17**
Von Der Heide, RJ - **56.325**
von der Heydt, R - 16.506, 53.402
von Grünau, M - **36.553**
von Loga, IS - 16.432
von Muhlenen, A - 33.506, **54.23**
Vul, E - **43.321**
Vuong, QC - **16.513**
Vurro, M - **21.16**
-
- W**
- Wade, A - 41.21
Wagemans, J - 26.542, 43.311, 53.408, **56.420**, 56.526
Walker, J - 36.403
Wallace, C - 33.452
Wallace, G - 41.16
Wallace, J - 53.550
Wallace, JM - **53.546**
Wallis, G - 25.12, **52.25**
Wallis, T - **35.13**
Wallis, TS - 53.552
Wallman, J - 51.23
Wallraven, C - 56.306
Walsh, V - 36.522
Walston, S - 32.25
Walther, DB - 62.14
Wandell, B - 26.544, 33.557
Wandell, BA - 54.11
Wang, A - 36.326
Wang, C - **16.516**
Wang, HX - **26.550**
Wang, L - 23.516, 26.415, **33.540**, 53.436, **54.25**
Wang, M - 63.328
Wang, R - **22.24**, 22.26
Wang, W - 26.401, 26.411
Wang, X - 16.427
Wang, Y - **36.321**
Wann, J - 33.321, 36.410, 53.513, 56.505
Ward, EJ - **36.328**
Warren, P - 36.402
Warren, PA - 23.554, **33.525**, 33.526
Warren, W - 36.405, 36.407, 53.507
Warren, WH - 53.503, 53.516
Waskom, ML - 23.440
Wasserman, E - 53.523
Watamaniuk, SN - 36.555
Watanabe, T - 16.543, 16.544, 23.553, 26.505, 32.27, 36.514, 36.516, 36.524, 42.22, 42.23
Watson, A - **56.544**
Watson, J - 23.432
Watt, SJ - 43.416
Wattam-Bell, J - 24.12, 26.511, 33.317
Waugh, SJ - 26.535, 53.543, **53.547**
Webb, B - 41.11
Webb, BS - 33.519
Weber, C - 23.313
Weber, R - **53.505**
Weber, S - **53.433**
Webster, K - **56.503**
Webster, M - 16.540, 23.406, 33.417, 33.418, 43.435
Weigelt, S - 56.310
Weightman, DA - 36.420
Weiler, J - 23.307, **23.308**
Weimer, S - 33.425
Weinshall, D - 56.546
Weinstein, A - 63.314
Weiss, S - **33.508**
Welchman, AE - 43.417, 51.13, 53.453, 63.436, 63.437, 63.438, 63.439
Wells, E - **33.513**
Welsh, T - 23.307
Wendel, L - 53.431
Weng, Q - **26.533**
Weng, X - 16.433, 53.436
Wenger, M - **16.510**
Wenger, MJ - 56.325
Wenner, J - 33.319
Wesner, MF - 36.517
West, G - 33.437, **36.413**, 53.304
Weston, R - 16.538
Wexler, M - **36.552**
Weymouth, A - 63.450
Wheatley, T - 36.414
Whitaker, D - 23.455
White, A - **26.453**
White, B - 16.516, **23.301**
Whitehead, R - 52.23
Whitney, D - 23.540, 26.424, 33.302, 36.425, 36.550, 36.554, 54.16, 55.26, 63.316, 63.317
Whitty, N - 23.539
Wichmann, F - 26.542
Wiebel, C - **56.438**
Wieczorek, K - **36.449**, 36.451
Wilcox, L - 63.441
Wilcox, LM - 63.442
Wilder, J - **26.402**
Wilke, C - 55.14
Wilkie, DR - 36.420
Wilkie, R - 23.551, 33.443, 53.501, 53.513, **53.520**
Willenbockel, V - 23.450
Williams, C - **23.324**, 23.531
Williams, M - **63.407**
Williams, V - 36.448
Wilmer, J - 36.530, 36.532, 56.301
Wilmot, K - 56.505
Wilson, AD - 63.457
Wilson, CE - 23.537
Wilson, D - 53.319, 53.437
Wilson, DE - **53.321**
Wilson, HR - 33.421
Wilson, KE - **63.458**
Winawer, J - 26.544, 33.557, **54.11**
Windridge, D - 16.406
Windsor, M - **53.308**
Winkler, A - 26.451
Winkler, P - **16.540**
Winter, H - 53.405
Wirxel, B - 55.14
Wismeijer, D - **23.317**
Witherspoon, R - **53.437**
Witt, J - 23.546, 53.531, 56.434
Witthoft, N - **23.541**
Wolfe, B - **33.302**
Wolfe, J - 53.431, 53.435, 53.440, 56.407, 56.441, **62.21**, 62.27
Wolfe, JM - 51.25, 56.406, 56.408, 56.409, 63.428
Wolfe, U - 26.321
Wolff, M - 21.15
Won, B - **33.407**
Wong, AC - **56.547**
Wong, E - 26.529
Wong, J - 26.431
Wong, YK - **22.17**
Wood, MJ - 36.301
Woodman, G - 36.327, 36.439, 62.25, 63.407
Woods, D - 43.305
Wright, C - **63.328**
Wright, H - 26.429
Wright, O - 26.511
Wright, T - 33.501, 33.509, **33.516**
Wu, C - **16.411**, 63.314, **63.329**
Wu, D - **53.530**
Wu, E - 63.417
Wu, Y - 56.514
Wulff, J - 36.431, **43.407**
Wurnitsch, N - **63.317**
Wyatte, D - **16.439**
Wyble, B - **33.554**, 54.28
-
- X**
- Xiao, D - 52.23
Xiao, J - 16.442
Xing, D - **26.546**, 26.547
Xu, B - **23.532**
Xu, G - 16.433
Xu, H - **43.427**
Xu, KZ - 24.24
Xu, T - 16.404, **16.405**
Xu, X - **41.17**, 53.526
Xu, Y - 16.425, 16.452, 16.512, 33.422, 36.520, 53.318, 53.541, **63.311**
Xuan, Y - 33.453
-
- Y**
- Yaguchi, H - 36.305
Yamaguchi, M - 56.321
Yamaguchi, MK - 33.320, 56.319, 56.326
Yamaguchi, T - 26.319
Yamamoto, H - 36.316
Yamamoto, K - 53.517
Yamanashi Leib, A - **23.540**
Yamanoi, T - 53.407
Yamashita, W - **56.326**
Yamauchi, Y - 26.319
Yampolsky, D - 32.25
Yang, F - **26.502**
Yang, H - 53.423, **61.23**
Yang, S - 36.533
Yang, X - **23.512**, **33.538**
Yang, Y - 26.401, 26.411
Yang, Z - **16.433**, 16.436, 26.538
Yantis, S - 53.310, 63.419
Yao, R - **56.527**
Yarrow, K - 61.17
Yashar, A - **43.322**, 53.444
Yazdanbakhsh, A - 16.527, **26.551**, 33.531
Yazdi, D - 56.415
Yeh, C - 26.546, **26.547**
Yeh, S - **22.16**, 33.505
Yen, S - 43.412
Yeshurun, Y - 62.23
Yi, M - 56.427
Yin, J - 26.401, 26.411
Yokosawa, K - **26.330**, 26.445, 36.430
Yonas, A - 23.536, 33.315, 56.327
Yoo, H - **43.425**
Yoo, S - **56.528**
Yoonessi, A - **33.536**
Yoshida, K - 26.319
Yoshioka, A - 36.316
Yoshizawa, T - **53.506**
Young, A - 43.446
Young, AH - **23.327**
Yovel, G - 23.521, 35.21, 35.22, 43.429
Yu, A - 16.409
Yu, C - **16.404**, 16.405, 22.24, 22.26, 36.501, 41.12, **56.548**
Yu, D - **33.408**
Yu, H - 52.22
Yuen, WS - 56.547
-
- Z**
- Zadra, J - **36.421**
Zadra, JR - 36.412
Zahabi, S - **53.555**
Zaidi, Q - 23.417, 26.313, 26.317, **33.535**, 42.15
Zannoli, M - **36.423**
Zaric, G - 26.505
Zehetleitner, M - 56.405
Zeiner, KM - **43.420**
Zelinsky, G - 23.322, **56.403**, 56.404, 56.417
Zenon, A - 32.21
Zenon, P - 23.428
Zerouali, Y - **43.455**
Zhang, G - 41.12
Zhang, H - **55.12**
Zhang, J - **22.26**, 25.25, **55.22**, 56.548
Zhang, NR - 53.402
Zhang, P - 26.322, **33.521**
Zhang, R - **26.517**

Zhang, S - **23.323**, 36.456, 51.26
zhang, w - **23.533**
Zhang, W - **63.405**, 63.420
Zhang, X - **16.517**, 23.403, 26.401,
26.411, 53.441, 53.521
Zhang, Z - **33.310**
Zhao, H - **53.507**
Zhao, J - **36.505**
Zhao, M - **36.407**, 53.442
Zhao, Y - 36.453
Zhaoping, L - 16.517, 23.403, 26.549,
43.420, **53.441**
Zhentao, Z - 43.432
Zhou, J - 33.327
Zhou, K - 54.22, 56.537
Zhou, T - 25.25
Zhou, X - **36.427**
Zhou, Y - 33.327, 36.526
Zhuo, Y - 25.25
Ziegler, R - 23.536
Ziesche, A - 33.307
Zimmermann, E - **24.25**
Zink, T - 33.431
Zirnsak, M - **24.24**
Zokaei, N - **63.421**
Zotov, A - 63.307
Zucker, S - **53.401**
Zughni, S - 32.13
Zuxiang, L - **43.432**